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Rupp et al.

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(54) **MAXIMUM TRAILER ANGLE DETERMINATION AND CONTROL FOR A TRAILER BACKUP ASSIST SYSTEM**

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(73) Assignee: **Ford Global Technologies**, Dearborn, MI (US)

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B62D 13/06	(2006.01)
B62D 15/02	(2006.01)

(52) **U.S. Cl.**

CPC ***B62D 13/06*** (2013.01); ***B62D 15/027*** (2013.01)

(58) **Field of Classification Search**

CPC B62D 15/25; B62D 6/008; B62D 6/00; B62D 13/06; B62D 6/003; B62D 6/002; B62D 7/159; B62D 15/02; B62D 15/021; B62D 15/029; B62D 13/005; B62D 15/028

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,904,222	B2 *	3/2011	Lee	B60D 1/30 340/932.2
7,925,409	B2 *	4/2011	Fry	B60T 8/1708 180/14.6

(Continued)

FOREIGN PATENT DOCUMENTS

DE	3931518 A1	4/1991
DE	9208595 U1	8/1992

(Continued)

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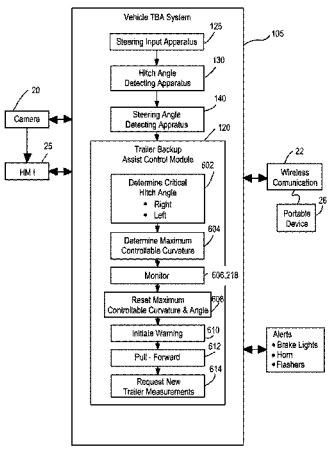
Assistant Examiner — Demetra Smith-Stewart

(74) *Attorney, Agent, or Firm* — Angela M. Brunetti; Raymond Copiellie

(57) **ABSTRACT**

The trailer backup assist system has a human machine interface coupled to a controller having a setup module, a calibration module, an activation module and a control module configured to receive trailer measurements, apply trailer measurements, activate and control vehicle systems to calibrate and implement a curvature control algorithm that controls the reverse movement of the vehicle-trailer combination in a manner consistent with a driver request. When incorrect trailer measurements have been entered, the trailer backup assist system recognizes the error, initiates a warning and requests corrective action to correct the trailer measurements. Default values for a maximum controllable curvature limit and a maximum controllable angle replace the limits calculated and applied by the calibration model that used incorrect trailer measurements, until corrected trailer measurements may be entered by the driver.

23 Claims, 12 Drawing Sheets



Related U.S. Application Data

continuation-in-part of application No. 13/336,060, filed on Dec. 23, 2011, now Pat. No. 8,909,426.

(60) Provisional application No. 61/477,132, filed on Apr. 19, 2011.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,010,252	B2 *	8/2011	Getman	B60T 8/1755 280/432
8,838,353	B2 *	9/2014	Wu	B60D 1/245 180/14.1
8,930,140	B2	1/2015	Trombley et al.	
2001/0044789	A1 *	11/2001	Widrow	G06N 3/061 706/14
2013/0268160	A1	10/2013	Trombley et al.	
2014/0188344	A1	7/2014	Lavoie	
2014/0188346	A1	7/2014	Lavoie	
2014/0200759	A1 *	7/2014	Lu	B60D 1/245 701/28
2014/0222288	A1	8/2014	Lavoie et al.	
2014/0343795	A1	11/2014	Lavoie	

FOREIGN PATENT DOCUMENTS

DE	10154612	A1	5/2003
EP	0418653	A1	3/1991
EP	2644477	A1	10/2013

* cited by examiner

FIG. 1

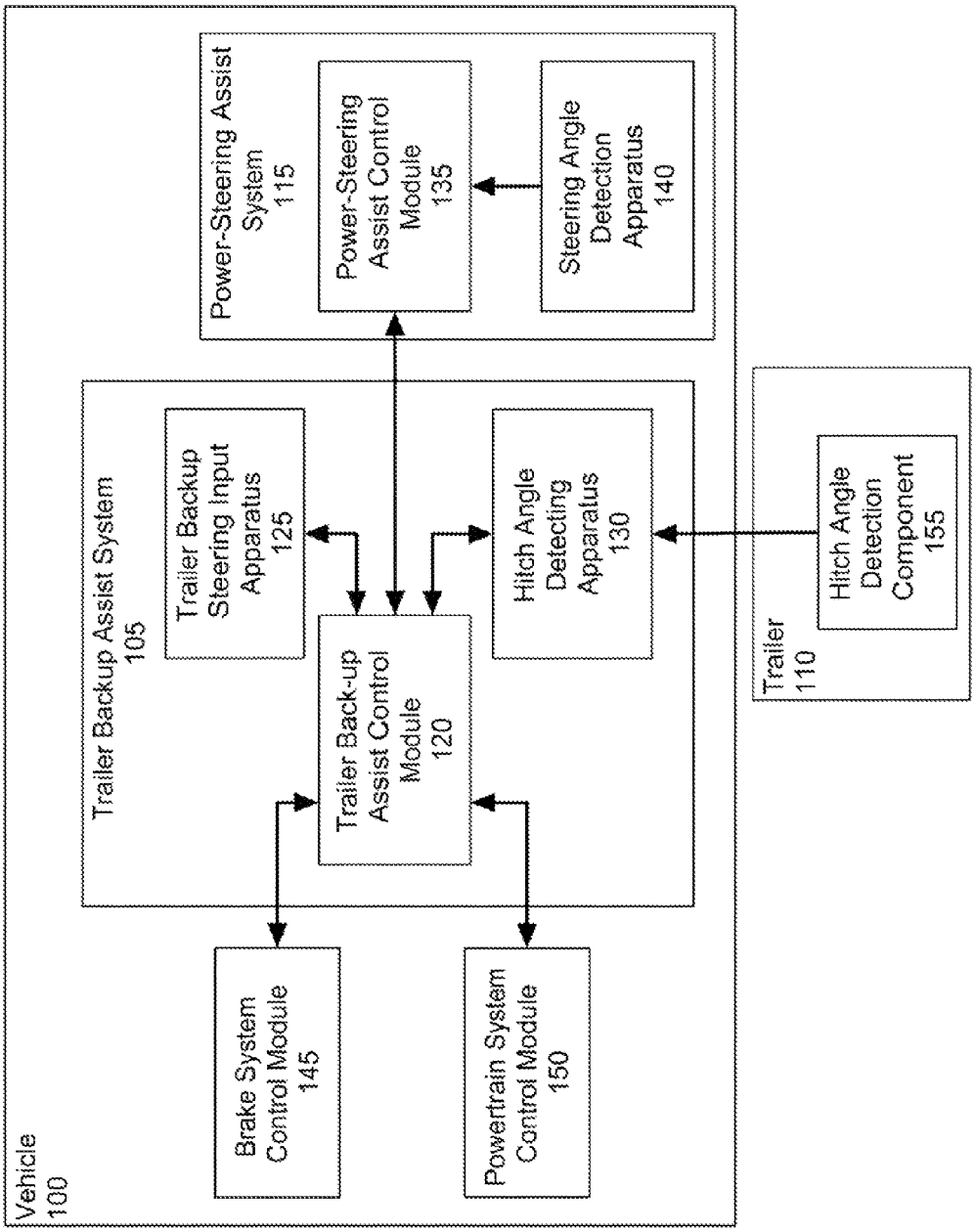
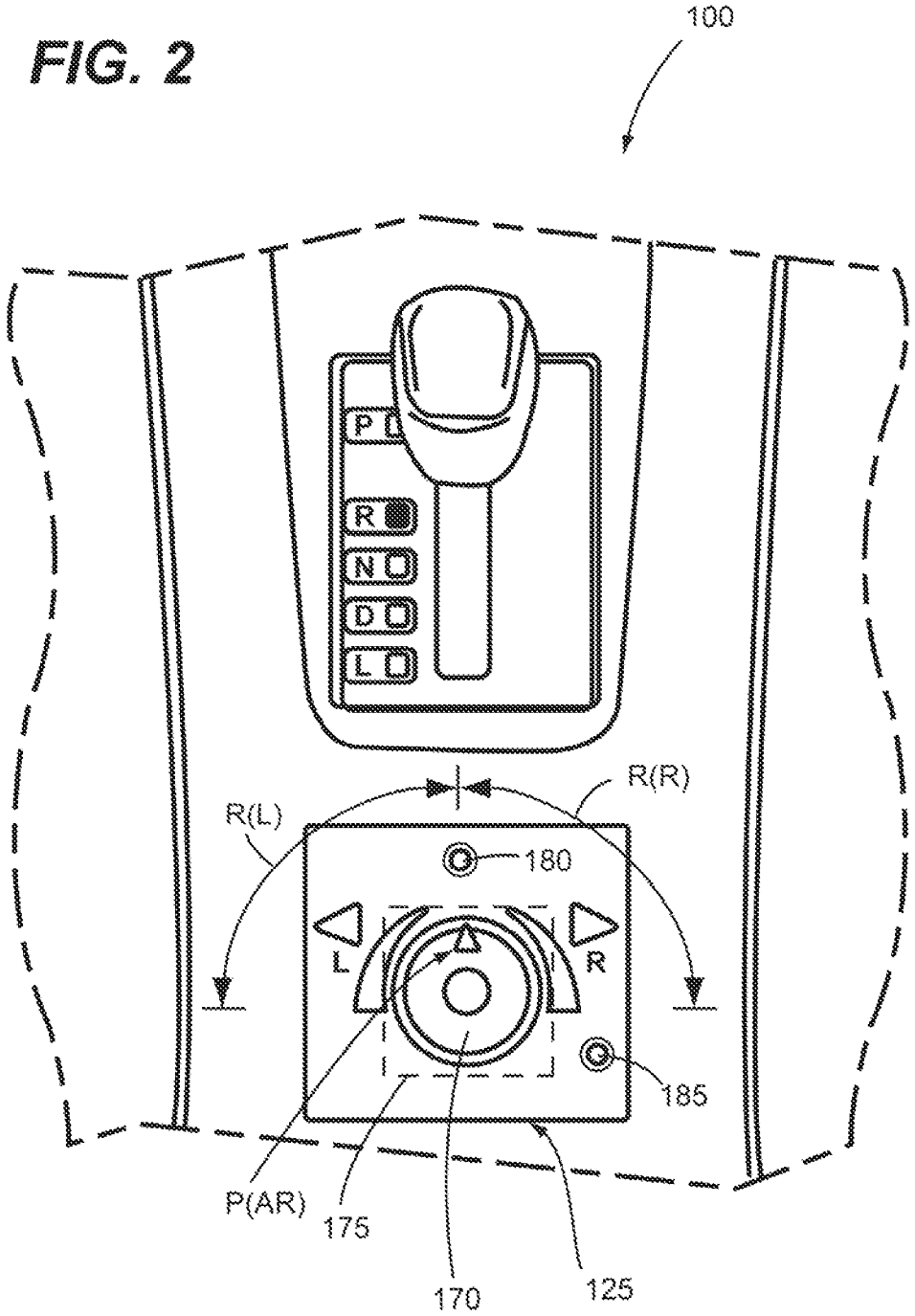

Vehicle
100
Trailer Backup Assist System
105
Trailer Back-up
Assist Control
Module
120
Trailer Backup
Steering Input
Apparatus
125
Hitch Angle
Detecting
Apparatus
130
Power-Steering Assist
System
115
Power-Steering
Assist Control
Module
135
Steering Angle
Detection
Apparatus
140
Brake System
Control Module
145
Powertrain System
Control Module
150
Trailer
110
Hitch Angle
Detection
Component
155

FIG. 2



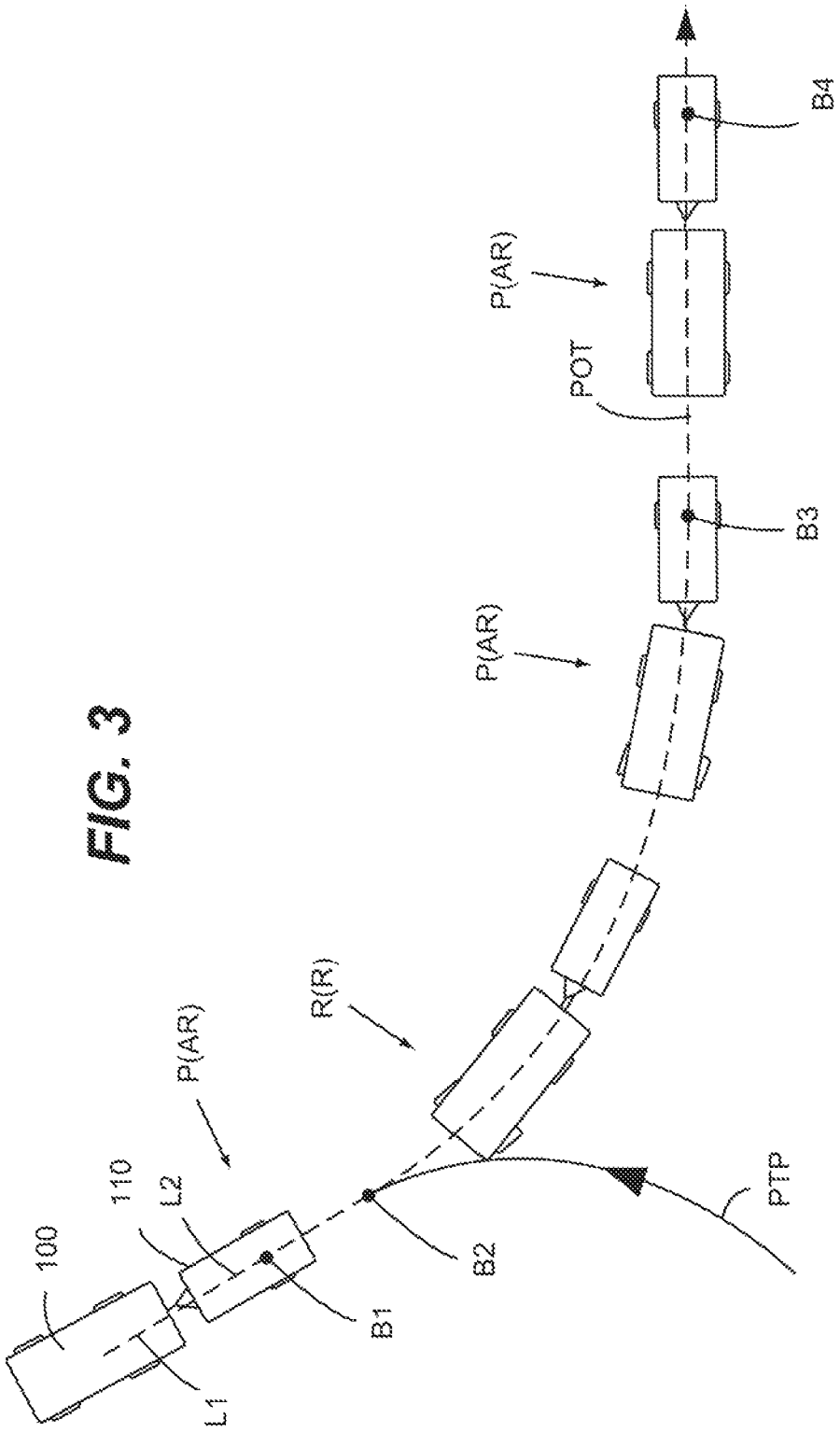


FIG. 3

FIG. 4

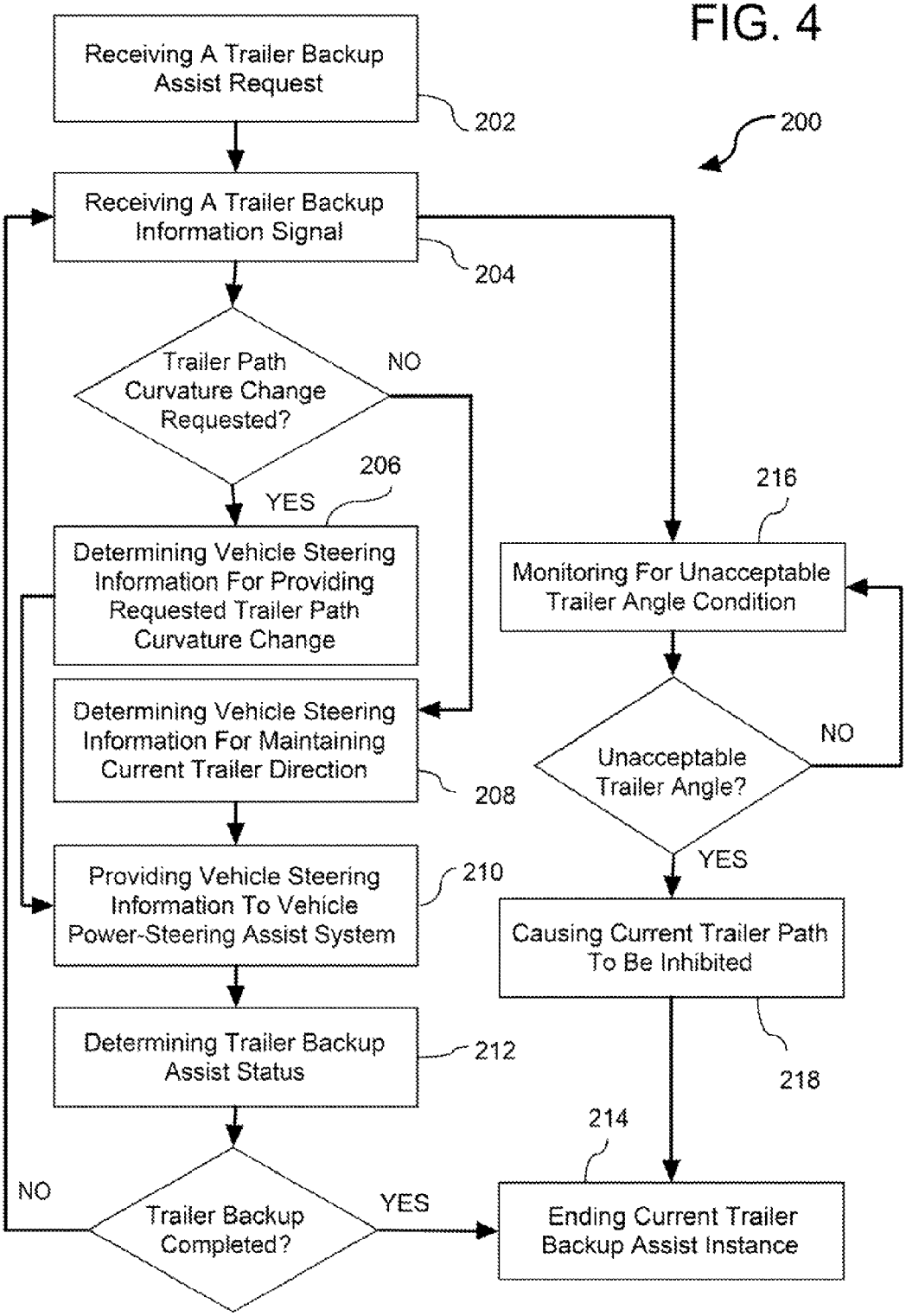

Receiving A Trailer Backup Assist Request
202
200
Receiving A Trailer Backup Information Signal
204
Trailer Path Curvature Change Requested?
NO
YES
206
Determining Vehicle Steering Information For Providing Requested Trailer Path Curvature Change
Determining Vehicle Steering Information For Maintaining Current Trailer Direction
208
Providing Vehicle Steering Information To Vehicle Power-Steering Assist System
210
Determining Trailer Backup Assist Status
212
Trailer Backup Completed?
NO
YES
214
Ending Current Trailer Backup Assist Instance
216
Monitoring For Unacceptable Trailer Angle Condition
Unacceptable Trailer Angle?
NO
YES
Causing Current Trailer Path To Be Inhibited
218

FIG. 5

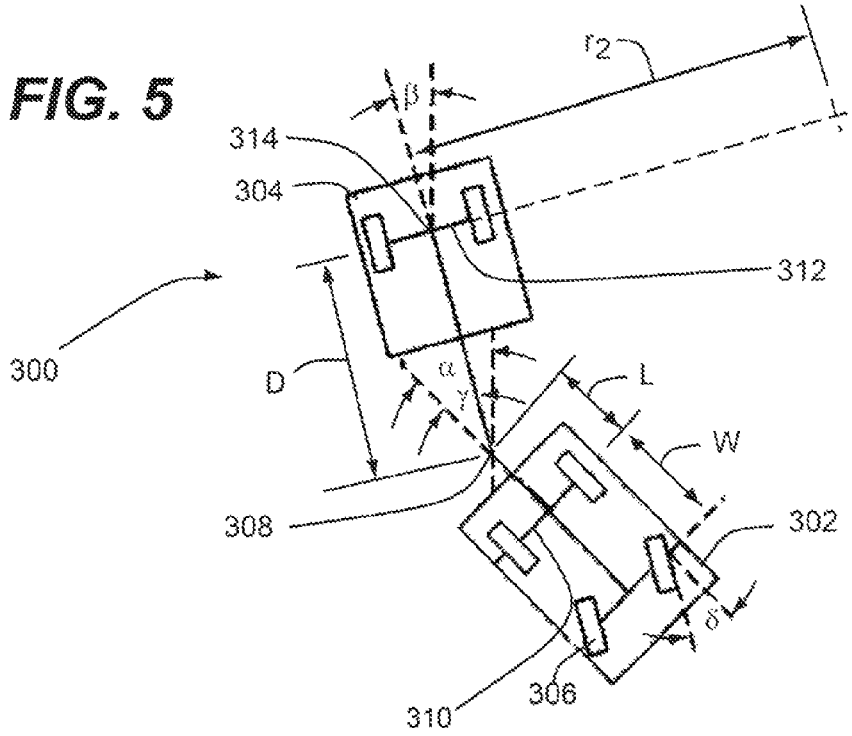
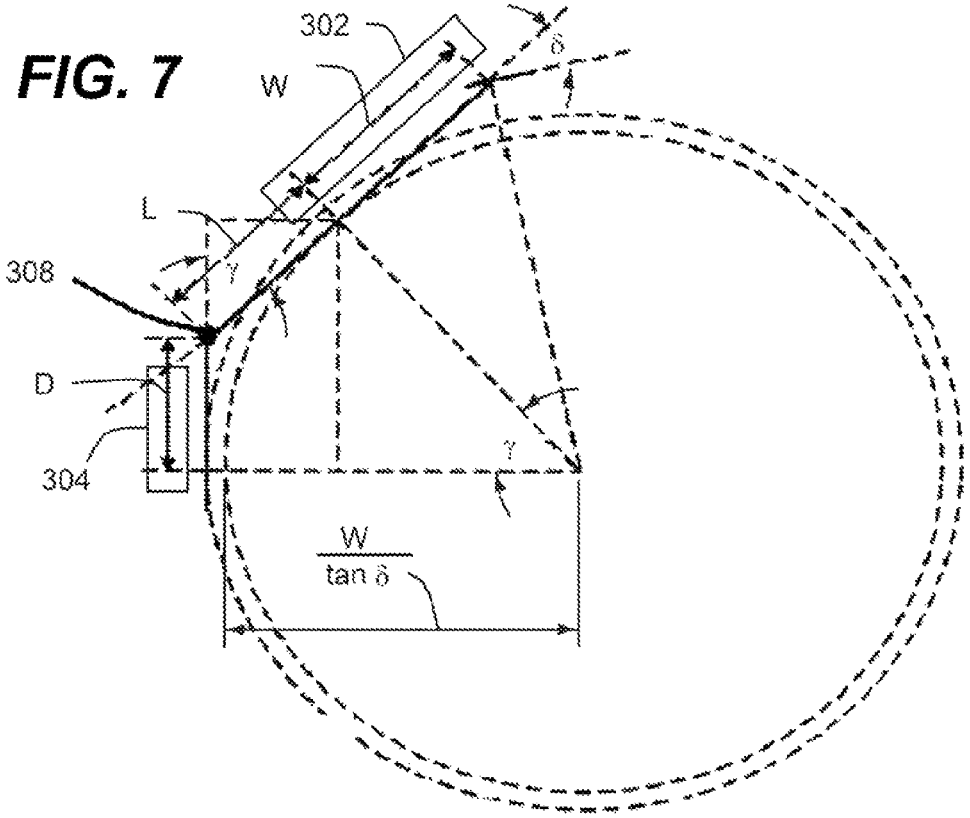

r2
β
314
304
312
300
D
α
γ
L
W
308
302
δ
310
306

FIG. 7


302
W
δ
L
γ
308
D
304
γ
W
tan δ

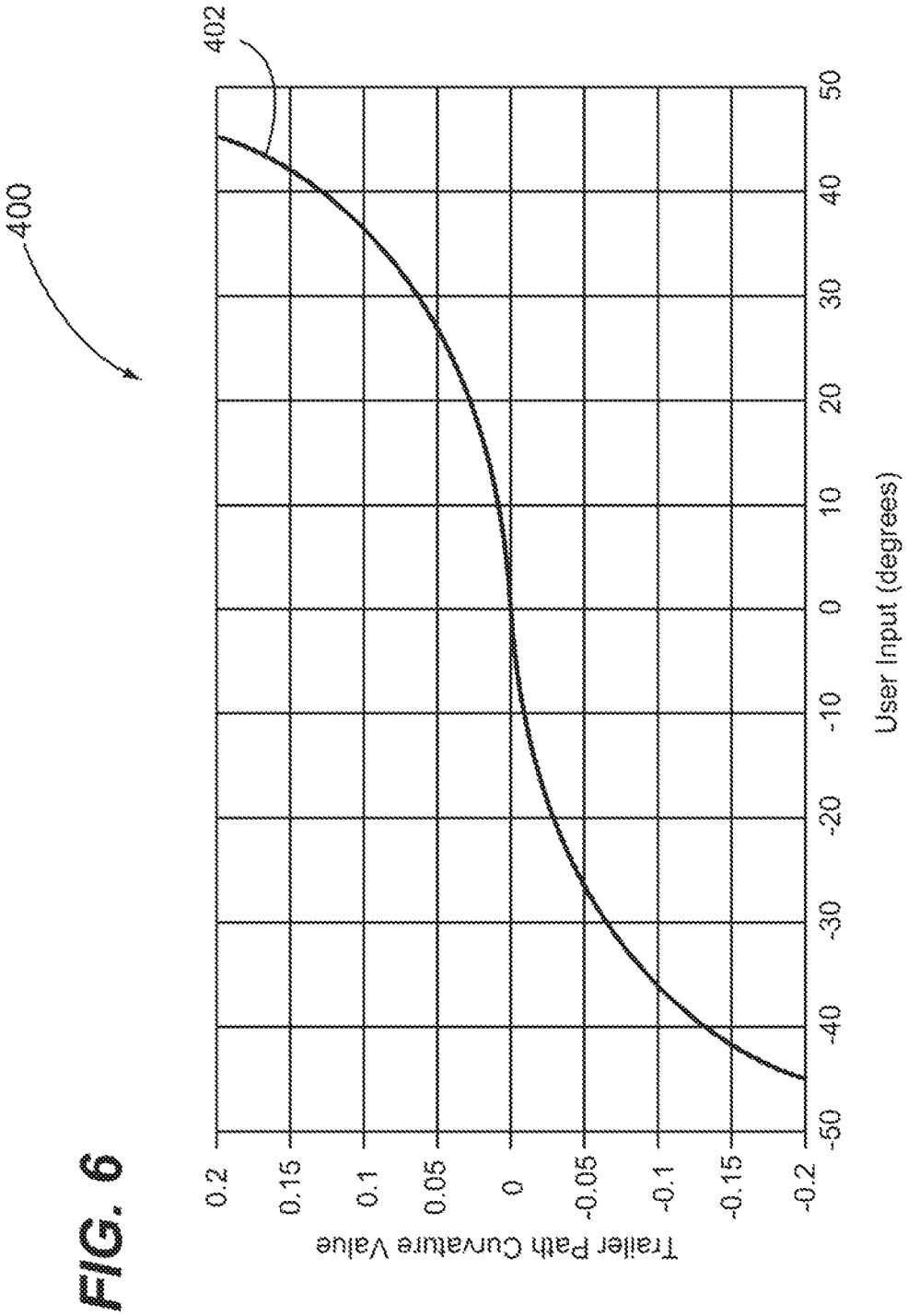
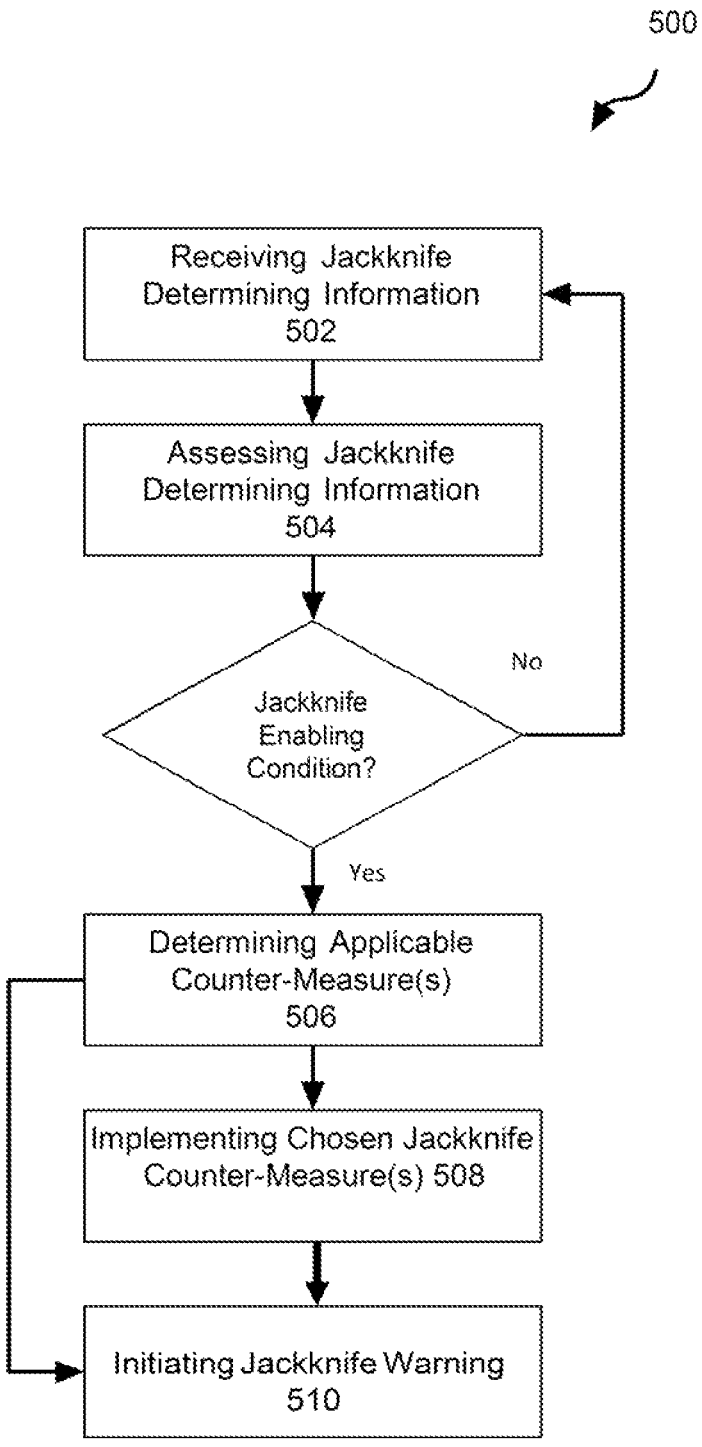

400
402
Trailer Path Curvature Value
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
User Input (degrees)
50
40
30
20
10
0
-10
-20
-30
-40
-50

FIG. 6

FIG. 8


500
Receiving Jackknife Determining Information 502
Assessing Jackknife Determining Information 504
Jackknife Enabling Condition?
No
Yes
Determining Applicable Counter-Measure(s) 506
Implementing Chosen Jackknife Counter-Measure(s) 508
Initiating Jackknife Warning 510

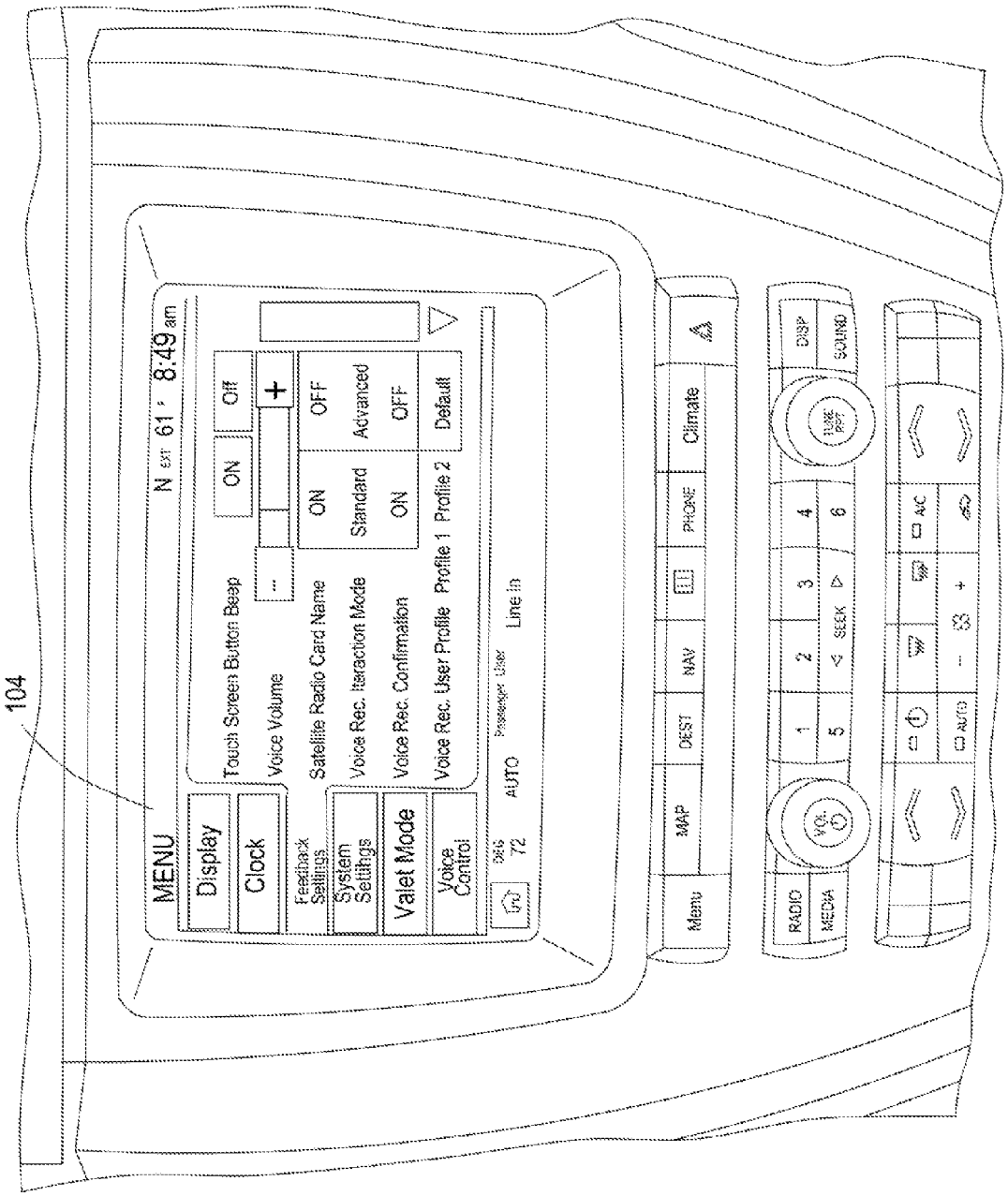

104
102
MENU
Display
Clock
Feedback Settings
System Settings
Valet Mode
Voice Control
N EXT 61° 8:49 am
Touch Screen Button Beep
Voice Volume
Satellite Radio Card Name
Voice Rec. Iteraction Mode
Voice Rec. Confirmation
Voice Rec. User Profile
ON
Off
OFF
Advanced
Standard
ON
OFF
Default
Profile 1
Profile 2
Line In
AUTO
72
MAP
DEST
NAV
PHONE
Climate
Menu
RADIO
MEDIA
SEEK
DISP
SOUND
A/C
AUTO

FIG. 9

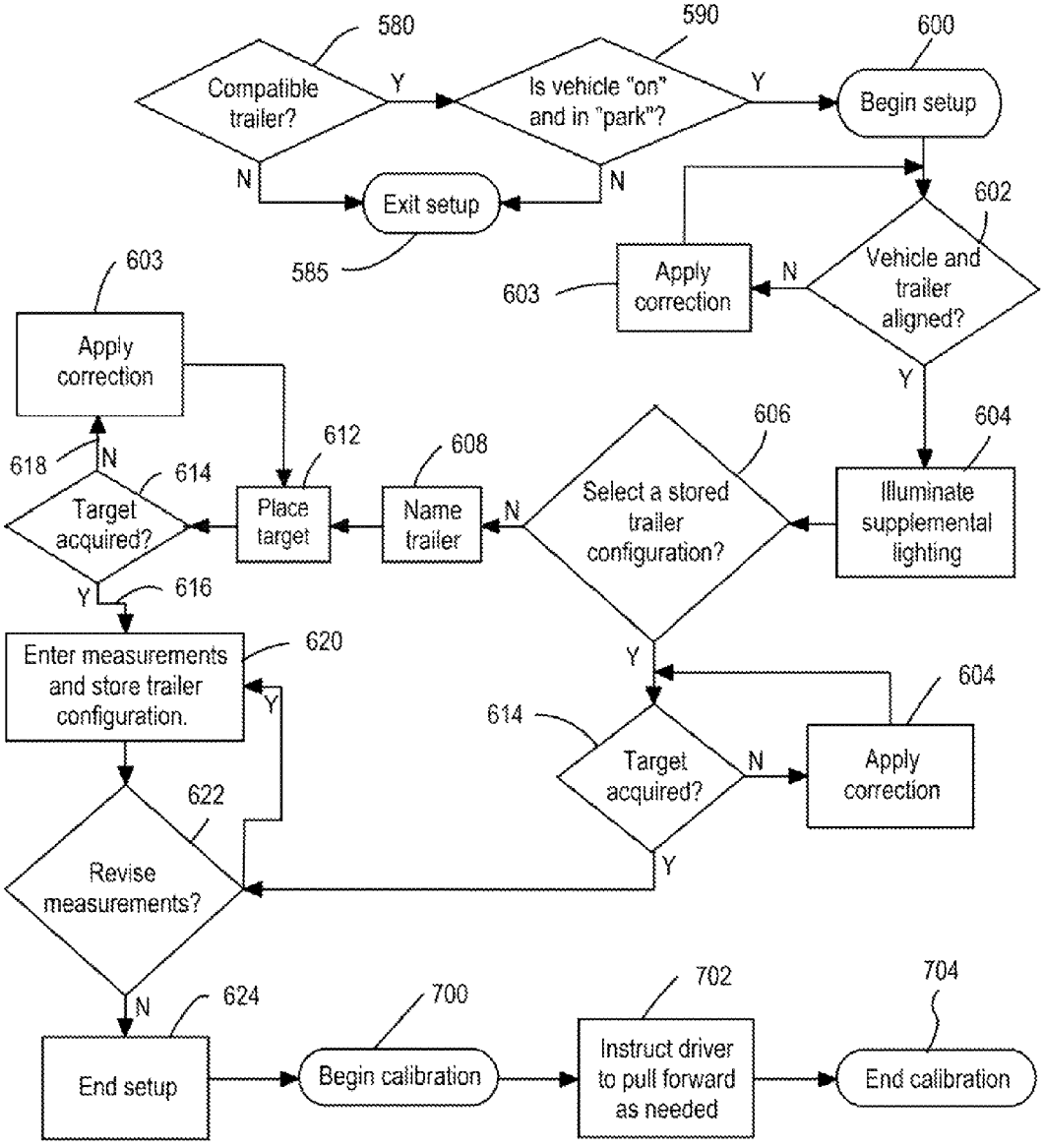

580
Compatible trailer?
Y
590
Is vehicle "on" and in "park"?
Y
600
Begin setup
N
N
Exit setup
585
602
Vehicle and trailer aligned?
N
603
Apply correction
603
Apply correction
Y
604
Illuminate supplemental lighting
606
Select a stored trailer configuration?
N
608
Name trailer
612
Place target
614
Target acquired?
618
N
Y
616
Enter measurements and store trailer configuration.
620
Y
622
Revise measurements?
N
624
End setup
Y
614
Target acquired?
N
604
Apply correction
Y
700
Begin calibration
702
Instruct driver to pull forward as needed
704
End calibration

FIG. 10

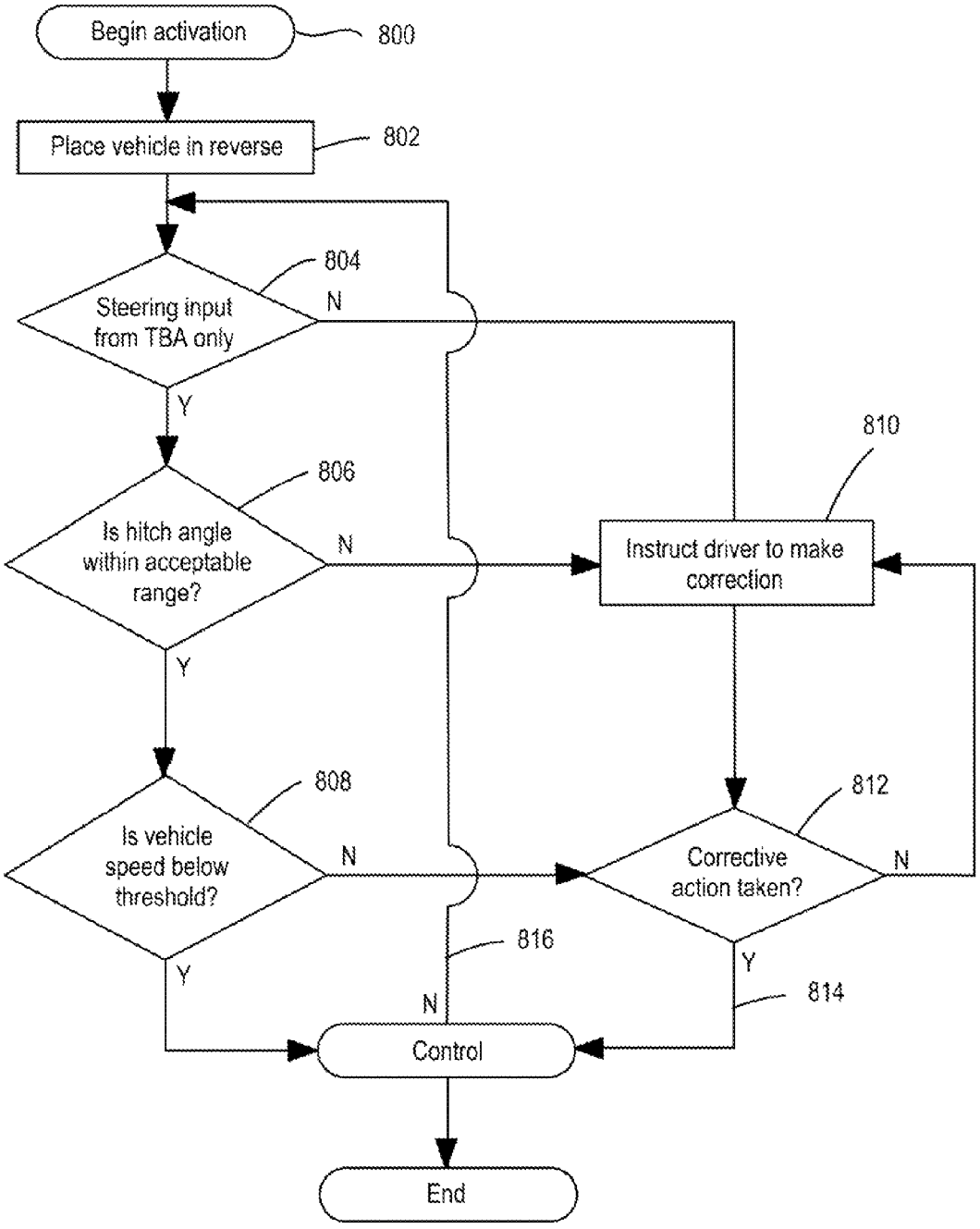

Begin activation
800
Place vehicle in reverse
802
804
Steering input from TBA only
N
Y
806
Is hitch angle within acceptable range?
N
Y
808
Is vehicle speed below threshold?
N
Y
810
Instruct driver to make correction
812
Corrective action taken?
N
Y
816
N
814
Control
End

FIG. 11

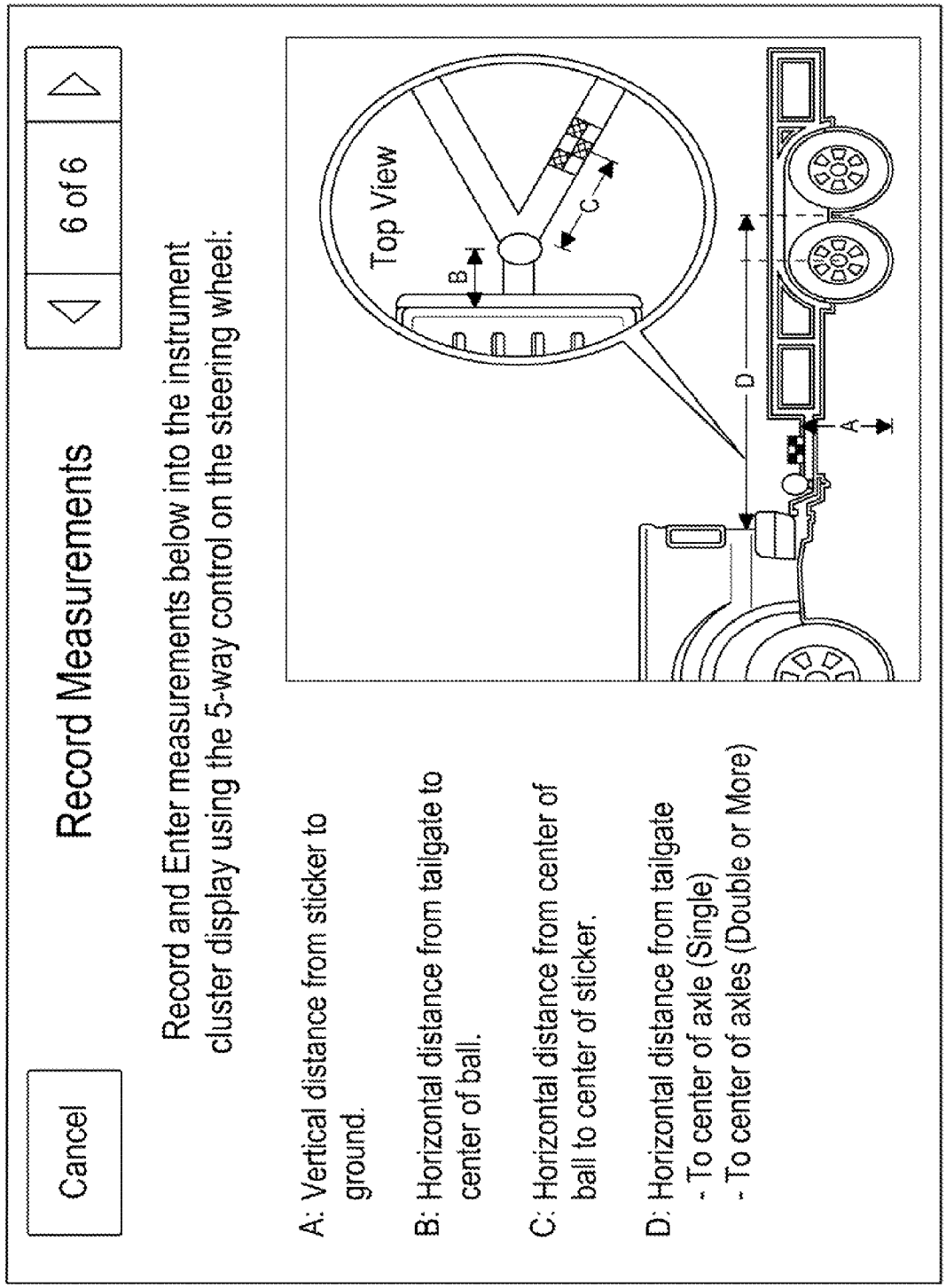

Cancel
Record Measurements
6 of 6
Record and Enter measurements below into the instrument cluster display using the 5-way control on the steering wheel:
A: Vertical distance from sticker to ground.
B: Horizontal distance from tailgate to center of ball.
C: Horizontal distance from center of ball to center of sticker.
D: Horizontal distance from tailgate
- To center of axle (Single)
- To center of axles (Double or More)
Top View
A
B
C
D

FIG. 12

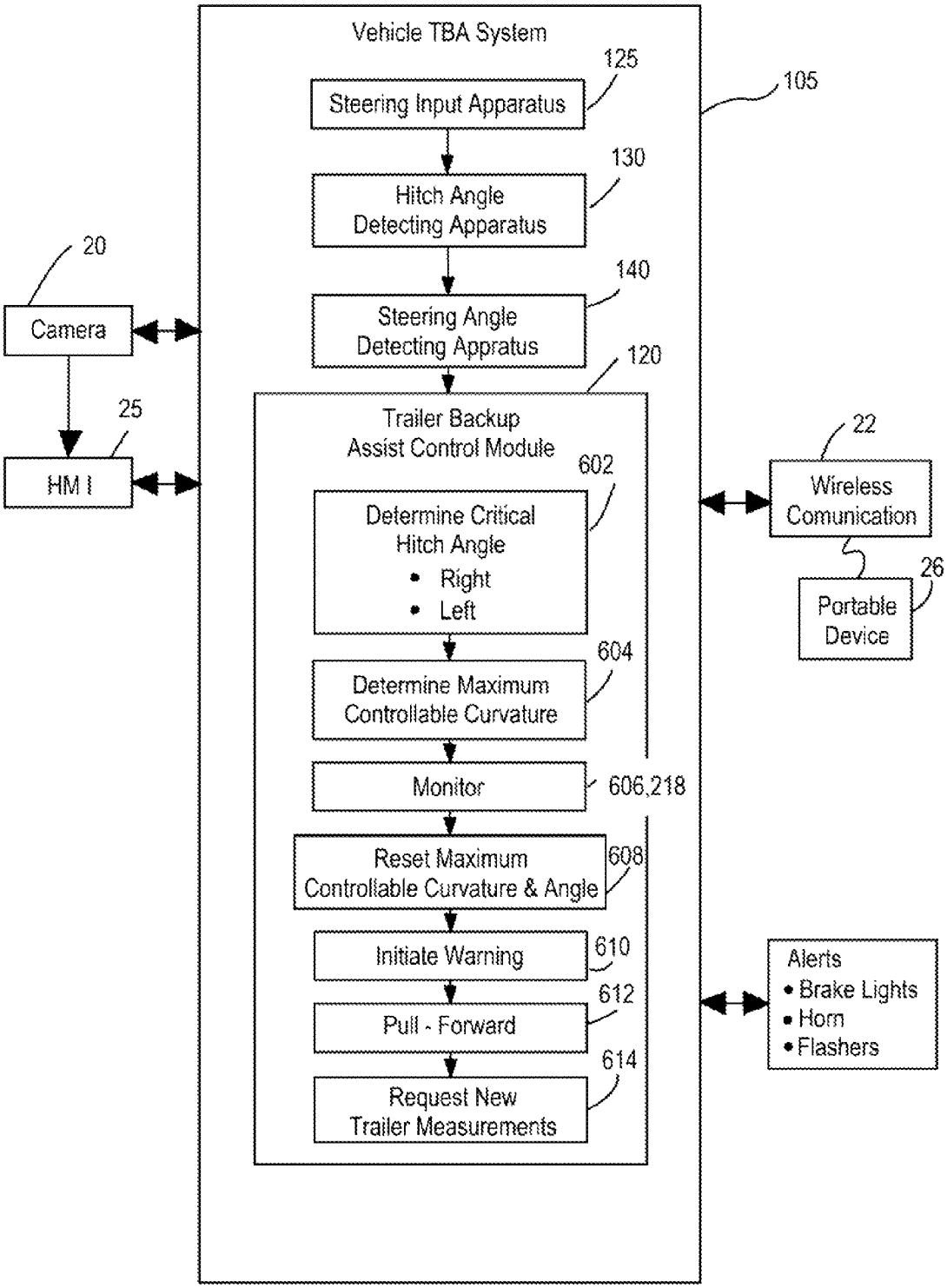

Vehicle TBA System
105
125
Steering Input Apparatus
130
Hitch Angle Detecting Apparatus
140
Steering Angle Detecting Appratus
120
Trailer Backup Assist Control Module
602
Determine Critical Hitch Angle
• Right
• Left
604
Determine Maximum Controllable Curvature
Monitor
606,218
608
Reset Maximum Controllable Curvature & Angle
610
Initiate Warning
612
Pull - Forward
614
Request New Trailer Measurements
20
Camera
25
HM I
22
Wireless Comunication
26
Portable Device
Alerts
• Brake Lights
• Horn
• Flashers

FIG. 13

MAXIMUM TRAILER ANGLE DETERMINATION AND CONTROL FOR A TRAILER BACKUP ASSIST SYSTEM

CROSS REFERENCE

This patent application is a continuation-in-part of co-pending U.S. patent application Ser. No. 14/059,835 filed on Oct. 22, 2013, entitled "TRAILER BACKUP ASSIST SYSTEM", which is a continuation-in-part of U.S. patent application Ser. No. 13/443,743 filed Apr. 10, 2012, entitled "DETECTION OF AND COUNTERMEASURES FOR JACKKNIFE ENABLING CONDITIONS DURING TRAILER BACKUP ASSIST", now allowed which is a continuation-in-part of co-pending U.S. patent application Ser. No. 13/336,060, which was filed Dec. 23, 2011, entitled "TRAILER PATH CURVATURE CONTROL FOR TRAILER BACKUP ASSIST", which claims priority from U.S. Provisional Patent Application No. 61/477,132, which was filed Apr. 19, 2011, which is entitled "TRAILER BACKUP ASSIST CURVATURE CONTROL", and both of which have a common applicant herewith and are being incorporated herein in their entirety by reference.

TECHNICAL FIELD

The disclosure made herein relates generally to driver assist and active safety technologies in vehicles, and more particularly to a trailer backup assist system.

BACKGROUND

It is well known that backing up a vehicle with a trailer attached is a difficult task for many drivers. This is particularly true for drivers that are untrained at backing with trailers such as, for example, those that drive with an attached trailer on an infrequent basis (e.g., have rented a trailer, use a personal trailer on an infrequent basis, etc.). One reason for such difficulty is that backing a vehicle with an attached trailer requires counter-steering that is opposite to normal steering when backing the vehicle without a trailer attached and/or requires braking to stabilize the vehicle-trailer combination before a jackknife condition occurs. Another reason for such difficulty is that small errors in steering while backing a vehicle with an attached trailer are amplified thereby causing the trailer to depart from a desired path.

To assist the driver in steering a vehicle with a trailer attached, a trailer backup assist system needs to know the driver's intention. One common assumption with known trailer backup assist systems is that a driver of a vehicle with an attached trailer wants to back up straight and the system either implicitly or explicitly assumes a zero curvature path for the vehicle-trailer combination. Unfortunately most of the real-world use cases of backing a trailer involve a curved path and, thus, assuming a path of zero curvature would significantly limit usefulness of the system. Some known systems assume that a path is known from a map or path planner. To this end, some known trailer backup assist systems operate under a requirement that a trailer back-up path is known before backing of the trailer commences such as, for example, from a map or a path planning algorithm. Undesirably, such implementations of the trailer backup assist systems are known to have a relatively complex Human Machine Interface (HMI) device to specify the path, obstacles and/or goal of the backup maneuver. Furthermore, such systems also require some way to determine how well the desired path is being followed and to know when the desired goal, or stopping point and orientation, has been met, using approaches such as cameras, inertial navigation, or high precision GPS. These requirements lead to a relatively complex and costly system.

Another reason backing a trailer can prove to be difficult is the need to control the vehicle in a manner that limits the potential for a jackknife condition to occur. A trailer has attained a jackknife condition when a hitch angle cannot be reduced (i.e., made less acute) while continuously backing up a trailer by application of a maximum steering input for the vehicle such as, for example, by moving steered front wheels of the vehicle to a maximum steered angle at a maximum rate of steering angle change. It is also possible while backing a trailer that a maximum allowable trailer curvature not be exceeded which, if the hitch angle becomes sufficiently large, contact may occur between a portion of the trailer and a portion of the vehicle. In the case of the jackknife angle being achieved, the vehicle must be pulled forward to relieve the hitch angle in order to eliminate the jackknife condition and, thus, allow the hitch angle to be controlled via manipulation of the steered wheels of the vehicle. However, in addition to the jackknife condition creating the inconvenient situation where the vehicle must be pulled forward, it can also lead to damage to the vehicle and/or trailer if certain operating conditions of the vehicle relating to its speed, engine torque, acceleration, and the like are not detected and counteracted. For example, if the vehicle is travelling at a suitably high speed in reverse and/or subjected to a suitably high longitudinal acceleration when the jackknife condition is achieved, the relative movement of the vehicle with respect to the trailer can lead to contact between the vehicle and trailer thereby damaging the trailer and/or the vehicle.

When the hitch angle becomes sufficiently large while backing a trailer it is not only possible to have contact between a portion of the trailer and the vehicle, but it is also possible that the vehicle could steer the trailer past a controllable curvature path. There is a need for determining a maximum trailer angle and a maximum controllable curvature. There is also a need for detecting when the determined maximum trailer angle and maximum controllable curvature may be incorrect. There is a need for resetting and correcting the determined maximum trailer angle and maximum controllable curvature. Lastly, there is a need for limiting trailer angle so that it is maintained within maximum left and right angles during backing of the trailer.

SUMMARY

Embodiments of the disclosed subject matter are directed to a system and method for assisting a driver with backing an attached trailer. TO BE COMPLETED UPON INVENTOR APPROVAL OF THE CLAIMS

These and other aspects, object, and features of the disclosed subject matter will be understood and appreciated by those skilled in the art upon studying the following specification, claims, and appended drawings.

DESCRIPTION OF DRAWINGS

FIG. **1** shows a vehicle-trailer combination, the vehicle being configured for performing trailer backup assist functionality in accordance with an embodiment of the disclosed subject matter embodiment.

FIG. **2** shows a preferred embodiment of the trailer backup steering input apparatus discussed in reference to FIG. **1**.

FIG. **3** shows an example of a trailer backup sequence implemented using the trailer backup steering input apparatus discussed in reference to FIG. **2**.

FIG. **4** shows a method for implementing trailer backup assist functionality in accordance with an embodiment of the disclosed subject matter.

FIG. **5** is a diagrammatic view showing a kinematic model configured for providing information utilized in providing trailer backup assist functionality in accordance with the disclosed subject matter.

FIG. **6** is a graph showing an example of a trailer path curvature function plot for a rotary-type trailer backup steering input apparatus configured in accordance with the disclosed subject matter.

FIG. **7** is a diagrammatic view showing a relationship between hitch angle and steered angle as it relates to determining a jackknife angle for a vehicle/trailer system in reverse or backing up.

FIG. **8** shows a method for implementing jackknife countermeasures functionality in accordance with an embodiment of the disclosed subject matter.

FIG. **9** shows a Human Machine Interface (HMI) device associated with the disclosed subject matter.

FIG. **10** shows a flow diagram associated with the disclosed subject matter.

FIG. **11** shows a flow diagram of the setup module of the disclosed subject matter.

FIG. **12** shows an example of an image displayed at the HMI device in accordance with the disclosed subject matter.

FIG. **13** shows a block diagram of the disclosed subject matter.

Elements and steps in the figures are illustrated for simplicity and clarity and have not necessarily been rendered according to any particular sequence. For example, steps that may be performed concurrently or in different order are illustrated in the figures to help to improve understanding of embodiments of the disclosed subject matter.

DETAILED DESCRIPTION

While various aspects of the disclosed subject matter are described with reference to a particular illustrative embodiment, the disclosed subject matter is not limited to such embodiments, and additional modifications, applications, and embodiments may be implemented without departing from the disclosed subject matter. In the figures, like reference numbers will be used to illustrate the same components. Those skilled in the art will recognize that the various components set forth herein may be altered without varying from the scope of the disclosed subject matter.

The disclosed subject matter is directed to providing trailer backup assist functionality in a manner that is relatively low cost and that offers an intuitive user interface. In particular, such trailer backup assist functionality provides for controlling curvature of a path of travel of a trailer attached to a vehicle (i.e., trailer path curvature control) by allowing a driver of the vehicle to specify a desired path of the trailer by inputting a desired trailer path curvature as the backup maneuver of the vehicle and trailer progresses. Although a control knob, a set of virtual buttons, or a touch screen can each be implemented for enabling trailer path curvature control, the disclosed subject matter is not unnecessarily limited to any particular configuration of interface through which a desired trailer path curvature is inputted. Furthermore, in the case where a steering wheel can be mechanically decoupled from steered wheels of the vehicle, the steering wheel can also be used as an interface through which a desired trailer path curvature is inputted. As will be discussed herein in greater detail, kinematical information of a system defined by the vehicle and the trailer are used to calculate a relationship (i.e., kinematics) between the trailer's curvature and the steering angle of the vehicle for determining steering angle changes of the vehicle for achieving the specified trailer path. Steering commands corresponding to the steering angle changes are used for controlling a steering system of the tow vehicle (e.g., electric power assisted steering (EPAS) system) for implementing steering angle changes of steered wheels of the vehicle to achieve (e.g., to approximate) the specified path of travel of the trailer. The trailer backup assist system automatically steers the vehicle-trailer combination as a driver uses the vehicle transmission, accelerator and brake to reverse the vehicle-trailer combination. The driver inputs a desired trailer curvature command by using an input device such as a trailer steering knob.

Trailer backup assist functionality is directed to implementing one or more countermeasures for limiting the potential of a jackknife condition being attained between a vehicle and a trailer being towed by the vehicle while backing up. In certain embodiments of the disclosed subject matter, curvature of a path of travel of the trailer (i.e., trailer path curvature control) can be controlled by allowing a driver of the vehicle to specify a desired path of the trailer by inputting a desired trailer path curvature as the backup maneuver of the vehicle and trailer progresses. Although a control knob, a set of virtual buttons, or a touch screen can each be implemented for enabling trailer path curvature control, the disclosed subject matter is not unnecessarily limited to any particular configuration of interface through which a desired trailer path curvature is inputted. Furthermore, in the case where a steering wheel can be mechanically decoupled from steered wheels of the vehicle, the steering wheel can also be used as an interface through which a desired trailer path curvature is inputted. As will be discussed herein in greater detail, kinematical information of a system defined by the vehicle and the trailer are used to calculate a relationship (i.e., kinematics) between the trailer's curvature and the steering angle of the vehicle for determining steering angle changes of the vehicle for achieving the specified trailer path. Steering commands corresponding to the steering angle changes are used for controlling a steering system of the tow vehicle (e.g., electric power assisted steering (EPAS) system) for implementing steering angle changes of steered wheels of the vehicle to achieve (e.g., to approximate) the specified path of travel of the trailer.

Trailer Backup Assist System

Referring to FIG. **1**, an embodiment of a vehicle **100** configured for performing trailer backup assist functionality in accordance with the inventive subject matter is shown. A trailer backup assist system **105** of the vehicle **100** controls the curvature of path of travel of a trailer **110** that is attached to the vehicle **100**. Such control is accomplished through interaction of a power assisted steering system **115** of the vehicle **100** and the trailer backup assist system **105**. During operation of the trailer backup assist system **105** while the vehicle **100** is being reversed, a driver of the vehicle **100** is sometimes limited in the manner in which he/she can make steering inputs via a steering wheel of the vehicle **100**. This is because in certain vehicles the trailer backup assist system **105** is in control of the power assisted steering system **115** and the power assisted steering system **115** is directly coupled to the steering wheel (i.e., the steering wheel of the vehicle **100** moves in concert with steered wheels of the vehicle **100**). As is discussed below in greater detail, a human machine interface (HMI) device of the backup assist system **105** is used for commanding changes in curvature of a path of the trailer **110** such as a knob, thereby decoupling such commands from being made at the steering wheel of the vehicle **100**. However, some vehicles configured to provide trailer backup assist

functionality in accordance with the inventive subject matter will have the capability to selectively decouple steering movement from movement of steerable wheels of the vehicle, thereby allowing the steering wheel to be used for commanding changes in curvature of a path of a trailer during such trailer backup assist.

The trailer backup assist system **105** includes a trailer backup assist control module **120**, a trailer backup steering input apparatus **125**, and a hitch angle detecting apparatus **130**. The trailer backup assist control module **120** is connected to the trailer backup steering input apparatus **125** and the hitch angle detecting apparatus **130** for allowing communication of information between them. It is disclosed herein that the trailer backup steering input apparatus can be coupled to the trailer backup assist control module **120** in a wired or wireless manner. The trailer backup assist system control module **120** is attached to a power-steering assist control module **135** of the power-steering assist system **115** for allowing information to be communicated between them. A steering angle detecting apparatus **140** of the power-steering assist system **115** is connected to the power-steering assist control module **135** for providing information thereto. The trailer backup assist system is also attached to a brake system control module **145** and a powertrain control module **150** for allowing communication of information between them. Jointly, the trailer backup assist system **105**, the power-steering assist system **115**, the brake system control module **145**, the powertrain control module **150**, and the gear selection device (PRNDL), define a trailer backup assist architecture configured in accordance with an embodiment of the disclosed subject matter.

The trailer backup assist control module **120** is configured for implementing logic (i.e., instructions) for receiving information from the trailer backup steering input apparatus **125**, the hitch angle detecting apparatus **130**, the power-steering assist control module **135**, the brake system control module **145**, and the powertrain control module **150**. The trailer backup assist control module **120** (e.g., a trailer curvature algorithm thereof) generates vehicle steering information as a function of all or a portion of the information received from the trailer backup steering input apparatus **125**, the hitch angle detecting apparatus **130**, the power-steering assist control module **135**, the brake system control module **145**, and the powertrain control module **150**. Thereafter, the vehicle steering information is provided to the power-steering assist control module **135** for affecting steering of the vehicle **100** by the power-steering assist system **115** to achieve a commanded path of travel for the trailer **110**.

The trailer backup steering input apparatus **125** provides the trailer backup assist control module **120** with information defining the commanded path of travel of the trailer **110** to the trailer backup assist control module **120** (i.e., trailer steering information). The trailer steering information can include information relating to a commanded change in the path of travel (e.g., a change in radius of path curvature) and information relating to an indication that the trailer is to travel along a path defined by a longitudinal centerline axis of the trailer (i.e., along a substantially straight path of travel). As will be discussed below in detail, the trailer backup steering input apparatus **125** preferably includes a rotational control input device for allowing a driver of the vehicle **100** to interface with the trailer backup steering input apparatus **125** to command desired trailer steering actions (e.g., commanding a desired change in radius of the path of travel of the trailer and/or commanding that the trailer travel along a substantially straight path of travel as defined by a longitudinal centerline axis of the trailer). In a preferred embodiment, the rotational control input device is a knob rotatable about a rotational axis extending through a top surface/face of the knob. In other embodiments, the rotational control input device is a knob rotatable about a rotational axis extending substantially parallel to a top surface/face of the knob.

Some vehicles (e.g., those with active front steer) have a power-steering assist system configuration that allows a steering wheel to be partially decoupled from movement of the steered wheels of such a vehicle. Accordingly, the steering wheel can be rotated independent of the manner in which the power-steering assist system of the vehicle controls the steered wheels (e.g., as commanded by vehicle steering information provided by a power-steering assist system control module from a trailer backup assist system control module configured in accordance with an embodiment of the disclosed subject matter). As such, in these types of vehicles where the steering wheel can be selectively decoupled from the steered wheels to allow independent operation thereof, trailer steering information of a trailer backup assist system configured in accordance with the disclosed subject matter can be provided through rotation of the steering wheel. Accordingly, it is disclosed herein that in certain embodiments of the disclosed subject matter, the steering wheel is an embodiment of a rotational control input device in the context of the disclosed subject matter. In such embodiments, the steering wheel would be biased (e.g., by an apparatus that is selectively engagable/activatable) to an at-rest position between opposing rotational ranges of motion.

The hitch angle detecting apparatus **130**, which operates in conjunction with a hitch angle detection component **155** of the trailer **110**, provides the trailer backup assist control module **120** with information relating to an angle between the vehicle **100** and the trailer **110** (i.e., hitch angle information). The hitch angle detecting apparatus **130** may be a camera-based apparatus such as, for example, an existing rear view camera of the vehicle **100** that images (i.e., visually monitors) a target (i.e., the hitch angle detection component **155**) attached the trailer **110** as the trailer **110** is being backed by the vehicle **100**. Preferably, but not necessarily, the hitch angle detection component **155** is a dedicated component (e.g., an item attached to/integral with a surface of the trailer **110** for the express purpose of being recognized by the hitch angle detecting apparatus **130**. Alternatively, the hitch angle detecting apparatus **130** can be a device that is physically mounted on a hitch component of the vehicle **100** and/or a mating hitch component of the trailer **110** for determining an angle between centerline longitudinal axes of the vehicle **100** and the trailer **110**. The hitch angle detecting apparatus **130** can be configured for detecting a jackknife enabling condition and/or related information (e.g., when a hitch angle threshold has been met).

The power-steering assist control module **135** provides the trailer backup assist control module **120** with information relating to a rotational position (e.g., angle) of the steering wheel angle and/or a rotational position (e.g., turning angle(s)) of steered wheels of the vehicle **100**. In certain embodiments of the disclosed subject matter, the trailer backup assist control module **120** can be an integrated component of the power steering assist system **115**. For example, the power-steering assist control module **135** can include a trailer back-up assist algorithm for generating vehicle steering information as a function of all or a portion of information received from the trailer backup steering input apparatus **125**, the hitch angle detecting apparatus **130**, the power-steering assist control module **135**, the brake system control module **145**, and the powertrain control module **150**.

The brake system control module **145** provides the trailer backup assist control module **120** with information relating to vehicle speed. Such vehicle speed information can be determined from individual wheel speeds as monitored by the brake system control module **145** or may be provided by an engine control module with signal plausibility. Vehicle speed may also be determined from an engine control module. In some instances, individual wheel speeds can also be used to determine a vehicle yaw rate and such yaw rate can be provided to the trailer backup assist control module **120** for use in determining the vehicle steering information. In certain embodiments, the trailer backup assist control module **120** can provide vehicle braking information to the brake system control module **145** for allowing the trailer backup assist control module **120** to control braking of the vehicle **100** during backing of the trailer **110**. For example, using the trailer backup assist control module **120** to regulate speed of the vehicle **100** during backing of the trailer **110** can reduce the potential for unacceptable trailer backup conditions. Examples of unacceptable trailer backup conditions include, but are not limited to, a vehicle over speed condition, a high hitch angle rate, trailer angle dynamic instability, a calculated theoretical trailer jackknife condition (defined by a maximum vehicle steering angle, drawbar length, tow vehicle wheelbase and an effective trailer length), or physical contact jackknife limitation (defined by an angular displacement limit relative to the vehicle **100** and the trailer **110**), and the like. It is disclosed herein that the backup assist control module **120** can issue a signal corresponding to a notification (e.g., a warning) of an actual, impending, and/or anticipated unacceptable trailer backup condition.

The powertrain control module **150** interacts with the trailer backup assist control module **120** for regulating speed and acceleration of the vehicle **100** during backing of the trailer **110**. As mentioned above, regulation of the speed of the vehicle **100** is necessary to limit the potential for unacceptable trailer backup conditions such as, for example, jackknifing and trailer angle dynamic instability. Similar to high-speed considerations as they relate to unacceptable trailer backup conditions, high acceleration and high dynamic driver curvature requests can also lead to such unacceptable trailer backup conditions.

Steering Input Apparatus

Referring now to FIG. **2**, an embodiment of the trailer backup steering input apparatus **125** discussed in reference to FIG. **1** is shown. A rotatable control element in the form of a knob **170** is coupled to a movement sensing device **175**. The knob **170** is biased (e.g., by a spring return) to an at-rest position P(AR) between opposing rotational ranges of motion R(R), R(L). A first one of the opposing rotational ranges of motion R(R) is substantially equal to a second one of the opposing rotational ranges of motion R(L), R(R). To provide a tactile indication of an amount of rotation of the knob **170**, a force that biases the knob **170** toward the at-rest position P(AR) can increase (e.g., non-linearly) as a function of the amount of rotation of the knob **170** with respect to the at-rest position P(AR). Additionally, the knob **170** can be configured with position indicating detents such that the driver can positively feel the at-rest position P(AR) and feel the ends of the opposing rotational ranges of motion R(L). R(R) approaching (e.g., soft end stops).

The movement sensing device **175** is configured for sensing movement of the knob **170** and outputting a corresponding signal (i.e., movement sensing device signal) to the trailer assist backup input apparatus **125** shown in FIG. **1**. The movement sensing device signal is generated as a function of an amount of rotation of the knob **170** with respect to the at-rest position P(AR), a rate movement of the knob **170**, and/or a direction of movement of the knob **170** with respect to the at-rest position P(AR). As will be discussed below in greater detail, the at-rest position P(AR) of the knob **170** corresponds to a movement sensing device signal indicating that the vehicle **100** should be steered such that the trailer **100** is backed along a substantially straight path (zero trailer curvature request from the driver) as defined by a centerline longitudinal axis of the trailer **110** when the knob **170** was returned to the at-rest position P(AR) and a maximum clockwise and anti-clockwise position of the knob **170** (i.e., limits of the opposing rotational ranges of motion R(R), R(L)) each correspond to a respective movement sensing device signal indicating a tightest radius of curvature (i.e., most acute trajectory) of a path of travel of the trailer **110** that is possible without the corresponding vehicle steering information causing a jackknife condition. In this regard, the at-rest position P(AR) is a zero curvature commanding position with respect to the opposing rotational ranges of motion R(R), R(L). It is disclosed herein that a ratio of a commanded curvature of a path of a trailer (e.g., radius of a trailer trajectory) and a corresponding amount of rotation of the knob can vary (e.g., non-linearly) over each one of the opposing rotational ranges of motion P(L), P(R) of the knob **170**. It is also disclosed therein that the ratio can be a function of vehicle speed, trailer geometry, vehicle geometry, hitch geometry and/or trailer load.

Use of the knob **170** decouples trailer steering inputs from being made at a steering wheel of the vehicle **100**. In use, as a driver of the vehicle **100** backs the trailer **110**, the driver can turn the knob **170** to indicate a desired curvature of a path of the trailer **110** to follow and returns the knob **170** to the at-rest position P(AR) for causing the trailer **110** to be backed along a straight line. Accordingly, in embodiments of trailer backup assist systems where the steering wheel remains physically coupled to the steerable wheels of a vehicle during backup of an attached trailer, a rotatable control element configured in accordance with the disclosed subject matter (e.g., the knob **170**) provides a simple and user-friendly means of allowing a driver of a vehicle to input trailer steering commands.

It is disclosed herein that a rotational control input device configured in accordance with embodiments of the disclosed subject matter (e.g., the knob **170** and associated movement sensing device) can omit a means for being biased to an at-rest position between opposing rotational ranges of motion. Lack of such biasing allows a current rotational position of the rotational control input device to be maintained until the rotational control input device is manually moved to a different position. Preferably, but not necessarily, when such biasing is omitted, a means is provided for indicating that the rotational control input device is positioned in a zero curvature commanding position (e.g., at the same position as the at-rest position in embodiments where the rotational control input device is biased). Examples of means for indicating that the rotational control input device is positioned in the zero curvature commanding position include, but are not limited to, a detent that the rotational control input device engages when in the zero curvature commanding position, a visual marking indicating that the rotational control input device is in the zero curvature commanding position, an active vibratory signal indicating that the rotational control input device is in or approaching the zero curvature commanding position, an audible message indicating that the rotational control input device is in of approaching the zero curvature commanding position, and the like.

It is also disclosed herein that embodiments of the disclosed subject matter can be configured with a control input

device that is not rotational (i.e., a non-rotational control input device). Similar to a rotational control input device configured in accordance with embodiments of the disclosed subject matter (e.g., the knob **170** and associated movement sensing device), such a non-rotational control input device is configured to selectively provide a signal causing a trailer to follow a path of travel segment that is substantially straight and to selectively provide a signal causing the trailer to follow a path of travel segment that is substantially curved. Examples of such a non-rotational control input device include, but are not limited to, a plurality of depressible buttons (e.g., curve left, curve right, and travel straight), a touch screen on which a driver traces or otherwise inputs a curvature for path of travel commands, a button that is translatable along an axis for allowing a driver to input path of travel commands, or joystick type input and the like.

The trailer backup steering input apparatus **125** can be configured to provide various feedback information to a driver of the vehicle **100**. Examples of situation that such feedback information can include, but are not limited to, a status of the trailer backup assist system **105** (e.g., active, in standby (e.g., when driving forward to reduce the trailer angle and zero trailer angle to remove bias), faulted, inactive, etc.), that a curvature limit has been reached (i.e., maximum commanded curvature of a path of travel of the trailer **110**), and/or a graphical representation of the vehicle and trailer orientation state. To this end, the trailer backup steering input apparatus **125** can be configured to provide a tactile feedback signal (e.g., a vibration through the knob **170**) as a warning if any one of a variety of conditions occur. Examples of such conditions include, but are not limited to, the trailer **110** approaching jackknife, the trailer backup assist system **105** has had a failure, the trailer backup assist system **105** has detected a fault, the trailer backup assist system **105** or other system of the vehicle **100** has predicted a collision on the present path of travel of the trailer **110**, the trailer backup system **105** has restricted a commanded curvature of a trailer's path of travel (e.g., due to excessive speed or acceleration of the vehicle **100**), and the like. Still further, it is disclosed that the trailer backup steering input apparatus **125** can use illumination (e.g., an LED **180**) and/or an audible signal output (e.g., an audible output device **185** or through attached vehicle audio speakers) to provide certain feedback information (e.g., notification/warning of an unacceptable trailer backup condition).

Referring now to FIGS. **2** and **3**, an example of using the trailer backup steering input apparatus **125** for dictating a curvature of a path of travel (POT) of a trailer (i.e., the trailer **110** shown in FIG. **1**) while backing up the trailer with a vehicle (i.e., the vehicle **100** in FIGS. **1** and **2**) is shown. In preparation of backing the trailer **110**, the driver of the vehicle **100** drives the vehicle **100** forward along a pull-thru path (PTP) to position the vehicle **100** and trailer **110** at a first backup position B**1**. In the first backup position B**1**, the vehicle **100** and trailer **110** are longitudinally aligned with each other such that a longitudinal centerline axis L**1** of the vehicle **100** is aligned with (e.g., parallel with or coincidental with) a longitudinal centerline axis L**2** of the trailer **110**. It is disclosed herein that such alignment of the longitudinal axes L**1**, L**2** at the onset of an instance of trailer backup functionality is not a requirement for operability of a trailer backup assist system configured in accordance with the disclosed subject matter.

After activating the trailer backup assist system **105** (e.g., before, after, or during the pull-thru sequence), the driver begins to back the trailer **110** by reversing the vehicle **100** from the first backup position B**1**. So long as the knob **170** of the trailer backup steering input apparatus **125** remains in the at-rest position P(AR), the trailer backup assist system **105** will steer the vehicle **100** as necessary for causing the trailer **110** to be backed along a substantially straight path of travel as defined by the longitudinal centerline axis L**2** of the trailer **110** at the time when backing of the trailer **110** began. When the trailer reaches the second backup position B**2**, the driver rotates the knob **170** to command the trailer **110** to be steered to the right (i.e., a knob position R(R) clockwise rotation). Accordingly, the trailer backup assist system **105** will steer the vehicle **100** for causing the trailer **110** to be steered to the right as a function of an amount of rotation of the knob **170** with respect to the at-rest position P(AR), a rate movement of the knob **170**, and/or a direction of movement of the knob **170** with respect to the at-rest position P(AR). Similarly, the trailer **110** can be commanded to steer to the left by rotating the knob **170** to the left. When the trailer reaches backup position B**3**, the driver allows the knob **170** to return to the at-rest position P(AR) thereby causing the trailer backup assist system **105** to steer the vehicle **100** as necessary for causing the trailer **110** to be backed along a substantially straight path of travel as defined by the longitudinal centerline axis **12** of the trailer **110** at the time when the knob **170** was returned to the at-rest position P(AR). Thereafter, the trailer backup assist system **105** steers the vehicle **100** as necessary for causing the trailer **110** to be backed along this substantially straight path to the fourth backup position B**4**. In this regard, arcuate portions of a path of travel POT of the trailer POT are dictated by rotation of the knob **170** and straight portions of the path of travel POT are dictated by an orientation of the centerline longitudinal axis L**2** of the trailer when the knob **170** is in/returned to the at-rest position P(AR).

In order to activate the trailer backup assist system described above in FIGS. **1** through **3**, the driver interacts with the trailer backup assist system and the trailer backup assist system interacts with the vehicle environment. The trailer backup assist system automatically steers as the driver reverses the vehicle. As discussed above, the driver controls the trailer trajectory by using a steering knob to input desired trailer curvature. The trailer backup assist algorithm determines the vehicle steering angle to achieve the desired trailer curvature, and the driver controls the throttle and brake while the trailer backup assist system controls the steering.

FIG. **4** shows a method **200** for implementing trailer backup assist functionality in accordance with an embodiment of the disclosed subject matter. In a preferred embodiment, the method **200** for implementing trailer backup assist functionality can be carried out using the trailer backup assist architecture discussed above in reference to the vehicle **100** and trailer **110** of FIG. **1**. Accordingly, trailer steering information is provided through use of a rotational control input device (e.g., the knob **170** discussed in reference to FIG. **2**).

An operation **202** is performed for receiving a trailer backup assist request. Examples of receiving the trailer backup assist request include activating the trailer backup assist system and providing confirmation that the vehicle and trailer are ready to be backed. After receiving a trailer backup assist request (i.e., while the vehicle is being reversed), an operation **204** is performed for receiving a trailer backup information signal. Examples of information carried by the trailer backup information signal include, but are not limited to, information from the trailer backup steering input apparatus **125**, information from the hitch angle detecting apparatus **130**, information from the power-steering assist control module **135**, information from the brake system control module **145**, and information from the powertrain control module **150**. It is disclosed herein that information from the trailer

backup steering input apparatus **125** preferably includes trailer path curvature information characterizing a desired curvature for the path of travel of the trailer, such as provided by the trailer backup steering input apparatus **125** discussed above in reference to FIGS. **1** and **2**. In this manner, the operation **204** for receiving the trailer backup information signal can include receiving trailer path curvature information characterizing the desired curvature for the path of travel of the trailer.

If the trailer backup information signal indicates that a change in curvature of the trailer's path of travel is requested (i.e., commanded via the knob **170**), an operation **206** is performed for determining vehicle steering information for providing the requested change in curvature of the trailer's path of travel. Otherwise, an operation **208** is performed for determining vehicle steering information for maintaining a current straight-line heading of the trailer (i.e., as defined by the longitudinal centerline axis of the trailer). Thereafter, an operation **210** is performed for providing the vehicle steering information to a power-steering assist system of the vehicle, followed by an operation **212** being performed for determining the trailer backup assist status. If it is determined that trailer backup is complete, an operation **214** is performed for ending the current trailer backup assist instance. Otherwise the method **200** returns to the operation **204** for receiving trailer backup information. Preferably, the operation for receiving the trailer backup information signal, determining the vehicle steering information, providing the vehicle steering information, and determining the trailer backup assist status are performed in a monitoring fashion (e.g., at a high rate of speed of a digital data processing device). Accordingly, unless it is determined that reversing of the vehicle for backing the trailer is completed (e.g., due to the vehicle having been successfully backed to a desired location during a trailer backup assist instance, the vehicle having to be pulled forward to begin another trailer backup assist instance, etc.), the method **200** will continually be performing the operations for receiving the trailer backup information signal, determining the vehicle steering information, providing the vehicle steering information, and determining the trailer backup assist status.

It is disclosed herein that the operation **206** for determining vehicle steering information for providing the requested change in curvature of the trailer's path of travel preferably includes determining vehicle steering information as a function of trailer path curvature information contained within the trailer backup information signal. As will be discussed below in greater detail, determining vehicle steering information can be accomplished through a low order kinematic model defined by the vehicle and the trailer. Through such a model, a relationship between the trailer path curvature and commanded steering angles of steered wheels of the vehicle can be generated for determining steering angle changes of the steered wheels for achieving a specified trailer path curvature. In this manner, the operation **206** for determining vehicle steering information can be configured for generating information necessary for providing trailer path curvature control in accordance with the disclosed subject matter.

In some embodiments of the disclosed subject matter, the operation **210** for providing the vehicle steering information to the power-steering assist system of the vehicle causes the steering system to generate a corresponding steering command as a function of the vehicle steering information. The steering command is interpretable by the steering system and is configured for causing the steering system to move steered wheels of the steering system for achieving a steered angle as specified by the vehicle steering information. Alternatively, the steering command can be generated by a controller, module or computer external to the steering system (e.g., a trailer backup assist control module) and be provided to the steering system.

In parallel with performing the operations for receiving the trailer backup information signal, determining the vehicle steering information, providing the vehicle steering information, and determining the trailer backup assist status, the method **200** performs an operation **216** for monitoring the trailer backup information for determining if an unacceptable trailer backup condition exists. Examples of such monitoring include, but are not limited to assessing a hitch angle to determine if a hitch angle threshold is exceeded, assessing a backup speed to determine if a backup speed threshold is exceeded, assessing vehicle steering angle to determine if a vehicle steering angle threshold is exceeded, assessing other operating parameters (e.g., vehicle longitudinal acceleration, throttle pedal demand rate and hitch angle rate) for determining if a respective threshold value is exceeded, and the like. Backup speed can be determined from wheel speed information obtained from one or more wheel speed sensors of the vehicle. If it is determined that an unacceptable trailer backup condition exists, an operation **218** is performed for causing the current path of travel of the trailer to be inhibited (e.g., stopping motion of the vehicle), followed by the operation **214** being performed for ending the current trailer backup assist instance. It is disclosed herein that prior to and/or in conjunction with causing the current trailer path to be inhibited, one or more actions (e.g., operations) can be implemented for providing the driver with feedback (e.g., a warning) that such an unacceptable trailer angle condition is impending or approaching. In one example, if such feedback results in the unacceptable trailer angle condition being remedied prior to achieving a critical condition, the method can continue with providing trailer backup assist functionality in accordance with operations **204-212**. Otherwise, the method can proceed to operation **214** for ending the current trailer backup assist instance. In conjunction with performing the operation **214** for ending the current trailer backup assist instance, an operation can be performed for controlling movement of the vehicle to correct or limit a jackknife condition (e.g., steering the vehicle, decelerating the vehicle, limiting magnitude and/or rate of driver requested trailer curvature input, limiting magnitude and/or rate of the steering command, and/or the like to preclude the hitch angle from being exceeded).

Curvature Control Algorithm

Turning now to a discussion of a kinematic model used to calculate a relationship between a curvature of a path of travel of a trailer and the steering angle of a vehicle towing the trailer, a low order kinematic model can be desirable for a trailer back-up assist system configured in accordance with some embodiments of the disclosed subject matter. To achieve such a low order kinematic model, certain assumptions are made with regard to parameters associated with the vehicle/trailer system. Examples of such assumptions include, but are not limited to, the trailer being backed by the vehicle at a relatively low speed, wheels of the vehicle and the trailer having negligible (e.g., no) slip, tires of the vehicle having negligible (e.g., no) lateral compliance, tires of the vehicle and the trailer having negligible (e.g., no) deformation, actuator dynamics of the vehicle being negligible, the vehicle and the trailer exhibiting negligible (e.g., no) roll or pitch motions.

As shown in FIG. **5**, for a system defined by a vehicle **302** and a trailer **304**, the kinematic model **300** is based on various

parameters associated with the vehicle **302** and the trailer **304**. These kinematic model parameters include:

δ: steering angle at steered front wheels **306** of the vehicle **302**;

α: yaw angle of the vehicle **302**;

β: yaw angle of the trailer **304**;

γ: hitch angle (γ=β−α);

W: wheel base of the vehicle **302**;

L: length between hitch point **308** and rear axle **310** of the vehicle **302**;

D: length between hitch point **308** and axle length **312** of the trailer **304** (axle length **312** may be an effective, or equivalent, axle length for a trailer having a multiple axle configuration; and

r_2: curvature radius for the trailer **304**.

The kinematic model **300** of FIG. **5** reveals a relationship between trailer path radius of curvature r_2 at the midpoint **314** of an axle **312** of the trailer **304**, steering angle δ of the steered wheels **306** of the vehicle **302**, and the hitch angle γ. As shown in the equation below, this relationship can be expressed to provide the trailer path curvature κ2 such that, if γ is given, the trailer path curvature κ2 can be controlled based on regulating the steering angle δ (where $\dot{\beta}$ is trailer yaw rate and $\dot{\eta}$ is trailer velocity).

$$\kappa_2 = \frac{1}{r_2} = \frac{\dot{\beta}}{\dot{\eta}} = \frac{\left(W + \frac{KV^2}{g}\right)\sin\gamma + L\cos\gamma\tan\delta}{D\left(\left(W + \frac{KV^2}{g}\right)\cos\gamma - L\sin\gamma\tan\delta\right)}$$

Or, this relationship can be expressed to provide the steering angle δ as a function of trailer path curvature κ2 and hitch angle γ.

$$\delta = \tan^{-1}\left(\frac{\left(W + \frac{KV^2}{g}\right)[\kappa_2 D\cos\gamma - \sin\gamma]}{DL\kappa_2\sin\gamma + L\cos\gamma}\right) = F(\gamma, \kappa_2, K)$$

Accordingly, for a particular vehicle and trailer combination, certain kinematic model parameters (e.g., D, W and L) are constant and assumed known. V is the vehicle longitudinal speed and g is the acceleration due to gravity. K is a speed dependent parameter which when set to zero makes the calculation of steering angle independent of vehicle speed. For example, vehicle-specific kinematic model parameters can be predefined in an electronic control system of a vehicle and trailer-specific kinematic model parameters can be inputted by a driver of the vehicle. Trailer path curvature κ_2 is determined from the driver input via a trailer backup steering input apparatus. Through the use of the equation for providing steering angle, a corresponding steering command can be generated for controlling a steering system (e.g., an actuator thereof) of the vehicle.

FIG. **6** shown an example of a trailer path curvature function plot **400** for a rotary-type trailer backup steering input apparatus (e.g., the trailer backup steering input apparatus **125** discussed above in reference to FIGS. **1** and **2**). A value representing trailer path curvature (e.g., trailer path curvature κ2) is provided as an output signal from the rotary-type trailer backup steering input apparatus as a function of user input movement. In this example, a curve **402** specifying trailer path curvature relative to user input (e.g., amount of rotation) at a rotary input device (e.g., a knob) is defined by a cubic function. However, a skilled person will appreciate that embodiments of the disclosed subject matter are not limited to any particular function between a magnitude and/or rate of input at a trailer backup steering input apparatus (e.g., knob rotation) and a resulting trailer path curvature value.

Jackknife Detection

Referring to FIG. **5**, in preferred embodiments of the disclosed subject matter, it is desirable to limit the potential for the vehicle **302** and the trailer **304** to attain a jackknife angle (i.e., the vehicle/trailer system achieving a jackknife condition). A jackknife angle γ(j) refers to a hitch angle γ that while backing cannot be overcome by the maximum steering input for a vehicle such as, for example, the steered front wheels **306** of the vehicle **302** being moved to a maximum steered angle δ at a maximum rate of steering angle change. The jackknife angle γ(j) is a function of a maximum wheel angle for the steered wheel **306** of the vehicle **302**, the wheel base W of the vehicle **302**, the distance L between hitch point **308** and the rear axle **310** of the vehicle **302**, and the length D between the hitch point **308** and the effective axle **312** of the trailer **304** when the trailer has multiple axles. The effective axle **312** may be the actual axle for a single axle trailer or an effective axle location for a trailer with multiple axles. When the hitch angle γ for the vehicle **302** and the trailer **304** achieves or exceeds the jackknife angle γ(j), the vehicle **302** must be pulled forward to reduce the hitch angle γ. Thus, for limiting the potential for a vehicle/trailer system attaining a jackknife angle, it is preferable to control the yaw angle of the trailer while keeping the hitch angle of the vehicle/trailer system relatively small.

Referring to FIGS. **5** and **7**, a steering angle limit for the steered front wheels **306** requires that the hitch angle γ cannot exceed the jackknife angle γ (j), which is also referred to as a critical hitch angle. Thus, under the limitation that the hitch angle γ cannot exceed the jackknife angle γ(j), the jackknife angle γ (j) is the hitch angle γ that maintains a circular motion for the vehicle/trailer system when the steered wheels **306** are at a maximum steering angle δ(max). The steering angle for circular motion with hitch angle is defined by the following equation.

$$\tan\delta_{max} = \frac{W\sin\gamma_{max}}{D + L\cos\gamma_{max}}$$

Solving the above equation for hitch angle allows jackknife angle γ(j) to be determined. This solution, which is shown in the following equation, can be used in implementing trailer backup assist functionality in accordance with the disclosed subject matter for monitoring hitch angle in relation to jackknife angle.

$$\cos\bar{\gamma} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2\alpha}$$

where,

$a = L^2\tan^2\delta(\max) + W^2$;

$b = 2LD\tan^2\delta(\max)$; and

$c = D^2\tan^2\delta(\max) - W^2$.

In certain instances of backing a trailer, a jackknife enabling condition can arise based on current operating parameters of a vehicle in combination with a corresponding hitch angle. This condition can be indicated when one or more

specified vehicle operating thresholds are met while a particular hitch angle is present. For example, although the particular hitch angle is not currently at the jackknife angle for the vehicle and attached trailer, certain vehicle operating parameters can lead to a rapid (e.g., uncontrolled) transition of the hitch angle to the jackknife angle for a current commanded trailer path curvature and/or can reduce an ability to steer the trailer away from the jackknife angle. One reason for a jackknife enabling condition is that trailer curvature control mechanisms (e.g., those in accordance with the disclosed subject matter) generally calculate steering commands at an instantaneous point in time during backing of a trailer. However, these calculations will typically not account for lag in the steering control system of the vehicle (e.g., lag in a steering EPAS controller). Another reason for the jackknife enabling condition is that trailer curvature control mechanisms generally exhibit reduced steering sensitivity and/or effectiveness when the vehicle is at relatively high speeds and/or when undergoing relatively high acceleration.

Jackknife Counter-Measures

FIG. **8** shows a method **500** for implementing jackknife countermeasures functionality in accordance with an embodiment of the disclosed subject matter for a vehicle and attached trailer. Trailer backup assist functionality in accordance with the disclosed subject matter can include jackknife countermeasures functionality. Alternatively, jackknife countermeasures functionality in accordance with an embodiment of the disclosed subject matter can be implemented separately from other aspects of trailer backup assist functionality.

The method **500** begins when operation **502** is performed for receiving jackknife determining information characterizing a jackknife enabling condition of the vehicle-trailer combination at a particular point in time (e.g., at the point in time when the jackknife determining information was sampled). Examples of the jackknife determining information includes, but are not limited to, information characterizing a hitch angle, information characterizing a vehicle accelerator pedal transient state, information characterizing a speed of the vehicle, information characterizing longitudinal acceleration of the vehicle, information characterizing a brake torque being applied by a brake system of the vehicle, information characterizing a powertrain torque being applied to driven wheels of the vehicle, and information characterizing the magnitude and rate of driver requested trailer curvature. The operation **502** for receiving jackknife determining information can be the first operation in a sampling process where jackknife determining information is sampled upon initiation of an instance of implementing jackknife countermeasures functionality. In this regard, jackknife determining information would be continually monitored such as, for example, by an electronic control unit (ECU) that carries out trailer backup assist (TBA) functionality. As discussed above in reference to FIG. **5**, a kinematic model representation of the vehicle and the trailer can be used to determine a jackknife angle for the vehicle-trailer combination. However, the disclosed subject matter is not unnecessarily limited to any specific approach for determining the jackknife angle.

After receiving the jackknife determining information, an operation **504** is performed for assessing the jackknife determining information for determining if the vehicle-trailer combination attained the jackknife enabling condition at the particular point in time. The objective of the operation **504** for assessing the jackknife determining information is determining if a jackknife enabling condition has been attained at the point in time defined by the jackknife determining information. If it is determined that a jackknife enabling condition is not present at the particular point in time, the method **500** returns to the operation **502** for receiving another instance of the jackknife determining information. If it is determined that a jackknife enabling condition is present at the particular point in time, an operation **506** is performed for determining an applicable counter-measure or counter-measures to implement. Accordingly, in some embodiments of the disclosed subject matter, an applicable counter-measure will be selected dependent upon a parameter identified as being a key influencer of the jackknife enabling condition. However, in other embodiments, an applicable counter-measure will be selected as being most able to readily alleviate the jackknife enabling condition. In still other embodiment, a pre-defined counter-measure or pre-defined set of counter-measures may be the applicable counter-measure(s).

The objective of a counter-measure in the context of the disclosed subject matter (i.e., a jackknife reduction counter-measure) is to alleviate a jackknife enabling condition. To this end, such a counter-measure can be configured to alleviate the jackknife enabling condition using a variety of different strategies. In a vehicle speed sensitive counter-measure strategy, actions taken for alleviating the jackknife enabling condition can include overriding and/or limiting driver requested trailer radius of curvature (e.g., being requested via a trailer backup steering input apparatus configured in accordance with the disclosed subject matter) as a function of vehicle speed (e.g., via a look-up table correlating radius of curvature limits to vehicle speed as shown in FIG. **6**). In a counter-measure strategy where trailer curvature requests are limited as a function of speed and driver curvature command transient rates, actions taken for alleviating the jackknife enabling condition can include rate limiting trailer curvature command transients as requested by a driver above a pre-defined vehicle speed whereas, under the pre-defined vehicle speed, the as-requested trailer curvature are not rate limited. In a torque limiting counter-measure strategy, actions taken for alleviating the jackknife enabling condition can include application of full available powertrain torque being inhibited when the jackknife enabling condition is present while the vehicle is above a pre-defined speed and application of full available powertrain torque being allowed when the vehicle speed is reduced below the pre-defined speed while in the torque inhibiting mode. As opposed to a fixed pre-defined speed, the torque limiting counter-measure strategy can utilize a speed threshold that is a function of hitch angle (i.e., speed threshold inversely proportional to hitch angle acuteness). In a driver accelerator pedal transient detection counter-measure strategy, actions taken for alleviating the jackknife enabling condition can include overriding and/or limiting driver requested trailer radius of curvature as a function of transient accelerator pedal requests (e.g., requested trailer radius of curvature limited when a large accelerator pedal transient is detected). In a hitch angle rate sensitive counter-measure strategy, actions taken for alleviating the jackknife enabling condition can include using hitch angle rate in a predefined or calculated mapping with current hitch angle position to limit driver requested trailer radius of curvature. Accordingly, in view of the disclosures made herein, a skilled person will appreciate that embodiments of the disclosed subject matter are not unnecessarily limited to a counter-measure strategy of any particular configuration.

As disclosed above, implementation of trailer backup assist functionality in accordance with the disclosed subject matter can utilize a kinematic model for determining steering control information, jackknife enabling conditions, and jackknife angle. Such a kinematic model has many parameters than can influence trailer curvature control effectiveness. Examples of these parameters include, but are not limited to,

the vehicle wheelbase, understeer gradient gain, vehicle track width, maximum steer angle at the vehicle front wheels, minimum turning radius of vehicle, maximum steering rate able to be commanded by the steering system, hitch ball to trailer axle length, and vehicle rear axle to hitch ball length. Sensitivity analysis for a given kinematic model can be used to provide an understanding (e.g., sensitivity) of the relationships between such parameters, thereby providing information necessary for improving curvature control performance and for reducing the potential for jackknife enabling conditions. For example, through an understanding of the sensitivity of the parameters of a kinematic model, scaling factors can be used with speed dependent jackknife counter-measures to reduce jackknife potential (e.g., for special applications such as short wheelbase conditions).

Still referring to FIG. **8**, after determining the applicable countermeasure(s), an operation **508** is performed for implementing the chosen jackknife countermeasure(s) and an operation **510** is performed for initiating a jackknife warning. As discussed above in regard to counter-measure strategies, implementing the jackknife counter-measure(s) can include commanding a speed controlling system of the vehicle to transition to an altered state of operation in which a speed of the vehicle is reduced, commanding the steering control system of the vehicle to transition to an altered state of operation in which a radius of curvature of a path of the trailer is increased, command the steering control system of the vehicle to transition to an altered state of operation in which a decrease in the radius of the curvature of the path of the trailer is inhibited, commanding a brake control system of the vehicle to apply brake torque to reduce vehicle speed/inhibit vehicle acceleration, and/or commanding a powertrain control system of the vehicle to inhibit full available powertrain torque from being delivered to driven wheels of the vehicle until another jackknife enabling parameter (e.g., vehicle speed) is below a defined threshold. In certain embodiments of the disclosed subject matter, the jackknife warning is provided to the driver using at least one vehicle control system through which the jackknife counter-measure is implemented. Speed reduction, in addition to applying the brakes, can be accomplished by any number of means such as, for example, limiting throttle inputs (e.g., via a terrain management feature) and/or transitioning a transmission to a reverse low gear if the vehicle is equipped with a multi-range reverse gear transmission. Examples of such system-specific warning approach include, but are not limited to, providing a warning through an accelerator pedal of the vehicle (e.g., via haptic feedback) if the counter-measure includes limiting speed of the vehicle and/or providing a warning through an input element (e.g., knob) of a trailer backup steering input apparatus of the vehicle (e.g., via haptic feedback if the counter-measure includes limiting driver requested trailer radius of curvature), through haptic seat vibration warning, through a visual warning (e.g., through a visual display apparatus of the towing vehicle) and/or through audible warnings (e.g., through an audio output apparatus of the towing vehicle), or the like. One embodiment of utilizing warnings relating to vehicle speed as it relates to onset or presence of a jackknife enabling condition includes implementation of a dual stage warning. For example, when a backing speed of the vehicle increases sufficiently for causing a speed of the vehicle to reach a lower (i.e., first) speed threshold during backing of the trailer, a driver of the vehicle would be provided with a first warning indication (e.g., via haptic, audible, and/or visual means as implemented by the trailer backup assist system) for informing the driver that there is the need to reduce the speed of the vehicle to alleviate or preclude the jackknife enabling condition. If the driver does not correspondingly respond by causing a speed of the vehicle to be reduced (or not to further increase) and the vehicle continues to gain speed such that it passes a higher (i.e., a second) speed threshold, the driver of the vehicle would be provided with a second warning indication (e.g., a more severe haptic, audible, and/or visual means as implemented by the trailer backup assist system) for informing the driver that there is an immediate need to reduce the speed of the vehicle to alleviate or preclude the jackknife enabling condition. The first and/or the second speed indication warnings can be implemented in conjunction with a respective speed limiting counter-measure or measures (e.g., the trailer backup assist system causing activation of a brake system of the vehicle and/or reducing a throttle position of the vehicle).

Human Machine Interface

In order to implement the control features discussed above with respect to methods described in FIG. **5** and FIG. **8**, a driver must interact with the trailer backup assist system **105** to configure the system **105**. The vehicle **100** is also equipped, as shown in FIG. **9**, with a Human Machine Interface (HMI) device **102** to implement trailer backup assist functionality through driver interaction with the HMI device **102**.

FIG. **9** shows an example of an HMI device **102** in the vehicle that a driver uses to interact with the trailer backup assist system **105**. The driver is presented with multiple menus **104** (only one example menu is shown in FIG. **9**) displayed by way of the HMI **102**. The HMI menus **104** assist the driver through modules (shown in FIGS. **10** and **11**) that setup **600**, calibrate **700**, and activate **800** the trailer back-up assist system **105** so that control methods **200**, **500** may be implemented to assist the driver with the backup of the trailer shown generally as a flow diagram in FIGS. **10** and **11**, and to be discussed in greater detail later herein. Each module is directed to particular elements, or features, which are used to configure the trailer backup assist system to accurately implement control methods **200**, **500**. While each module is described with reference to particular features of the disclosed subject matter, it should be noted that each module is not necessarily limited to the particular features described in the examples herein. It is possible to rearrange the modules or to replace elements or features of a module without departing from the scope of the disclosed subject matter.

The trailer backup assist system **105** will guide a driver through the steps necessary to connect a trailer and attach a target. The driver may activate the setup by way of the backup steering input apparatus **125**, for example by turning or pushing the rotary knob, or my merely making a selection for the Trailer Backup Assist System from a menu on the HMI device **102**. Referring to FIG. **10**, a driver initiates the trailer backup assist system through the trailer backup assist steering input apparatus. In the case of a rotary knob, the driver presses or rotates the knob to initiate the trailer backup assist system. The system will guide the driver through the steps of connecting **580** a compatible trailer **110**. A compatible trailer is one that pivots at a single point relative to the vehicle and behind the rear axle of the vehicle.

Once the system is selected by either the trailer backup steering input apparatus **125** or the HMI device **105**, the system will guide the driver to prepare the vehicle and vehicle trailer combination as necessary. The vehicle **100** should be turned "on" and the vehicle **100** should be in "park" **590**. In the event the vehicle **100** is on but is traveling at a speed that is greater than a predetermined limit, for example five miles per hour, the trailer backup assist system **105** will become inactive and inaccessible to the driver. The trailer backup assist system **105** setup module **600** will not begin or will be

exited **585**. If the type of trailer **110** selected by the driver is a trailer **110** that is not compatible with the trailer backup assist system **105**, the setup module **600** will be exited **585** or will not begin. In the event, the trailer **110** is compatible with the trailer backup assist system **105**, the setup module **600** verifies that the vehicle **100** gear shift mechanism is in "park". Again, in the event the vehicle is not "on" and the gear shift mechanism is not on "park", the setup module will not begin **585**.

Upon connection **580** of a compatible trailer **110**, the vehicle **100** being "on" **590** and the vehicle **100** being in "park" **590**, the HMI **102** will present a menu **104** that has a "Towing" mode option to be selected by the driver. The driver selects "Towing" mode and a menu **104** is presented that provides a "Trailer Options" selection. The driver then selects a "Trailer Options" mode from the "Towing" menu. The driver is prompted to either "add a trailer" or "select a trailer" from a menu **104** presented on the HMI device and the "Setup" module **600** of the disclosed subject matter has begun. For certain camera-based trailer angle detection systems, an operation **602** is performed wherein a warning menu may be presented to the driver, by way of the HMI, informing the driver that the trailer must be in a straight line, meaning there is no angle at the hitch between the vehicle and the trailer. The warning indicates that the driver may need to take corrective action, for example, pull the vehicle forward in order to align the trailer and the vehicle as required for the setup **600**. A generic or static graphic may be presented by way of the HMI **102** to assist the driver in visually recognizing the alignment between the trailer **110** and the vehicle **100** that is necessary in order to properly setup and calibrate the trailer backup assist system **105**. The driver applies any corrections **603** in that the driver makes any necessary adjustment he has been alerted to and indicates, by acknowledging that corrective actions have been applied **603** and that the trailer is in line with the vehicle. Other trailer angle detection systems may not need the driver to straighten the trailer during setup mode.

To aid the driver in the setup process, the reverse back lights, or any other supplemental lighting that may be available on the vehicle, are illuminated **604**. In the event the trailer is a new trailer, one that hasn't been attached to the vehicle before or hasn't been previously stored in the trailer backup assist system, the driver is presented **606** with an option to either name the trailer or select a previously stored trailer configuration. Naming the trailer **608** allows the trailer to be easily identified the next time it is attached to the vehicle so that the driver doesn't have to repeat the setup process. The driver either enters a unique name to identify the trailer that is to be stored in the trailer backup assist system or selects a previously stored trailer configuration associated with the attached trailer. The trailer backup assist system will not allow more than one trailer to have the same name. Therefore, if a driver attempts to name a trailer using a name that has already been applied to a previously stored trailer configuration, the HMI will display a message to the driver indicating so and requesting the driver enter a different name for the trailer configuration. In the case where a previously stored trailer configuration is available and selected **610** by the driver, certain steps in the setup process may be skipped.

The following discussion is directed to a first time trailer configuration for a camera-based trailer angle detection system. The driver is instructed **612** to place a hitch angle target on the trailer that is used for calibration purposes. A generic static image may be displayed on the HMI that provides direction to the driver as to placement of a target on the trailer that is used for hitch angle detection. The target placement is dependent upon the type of trailer being towed and therefore, options may be presented to the driver to aid the driver in selecting an appropriate trailer type. The static image may indicate areas that are acceptable for target placement as well as areas that are unacceptable for target placement. The static image indicating the appropriate areas for attaching the target may be an overlay of the rear view of the trailer hitch. Once the driver attaches the target to the trailer and indicates by way of the HMI that the target has been attached to the trailer the setup mode provides **614** visual feedback to the driver identifying that the target has been located, or acquired. The driver acknowledges **616**, by way of the HMI, that the target has been properly identified by the trailer backup assist system. Similarly, for a previously stored trailer configuration, the trailer will already have a target placed thereon. The trailer backup assist system will acquire the target and provide **614** visual feedback to the driver confirming acquisition of the target.

In the event the target is not acquired **614** after a predetermined amount of time lapses, the driver is notified **618** of the need to reposition the target and presented with possible corrective measures that may be taken. Possible corrective measures may be presented to the driver such as cleaning the camera lens, cleaning the target, replacing the target if it has been damaged or faded, pulling the vehicle-trailer combination forward to improve lighting conditions around the camera and/or target, and moving the target to an acceptable location. The driver applies the necessary corrections **603**. As mentioned above, some trailer angle detection systems may not require the driver to attach a target to the trailer during set up mode. The target and acquisition of the target are directed to camera-based trailer angle detection systems.

When the target is acquired **614** by the trailer backup assist system and the driver has acknowledged **616** the acquisition, the driver is then prompted through a series of menus to input **620** trailer measurement information that may be stored in the trailer backup assist system for a trailer configuration that is to be associated with the named trailer. The next time the same trailer is attached to the vehicle, its unique trailer configuration will already be stored and progress through the setup module will be faster or, in some cases, may be skipped entirely. Generic static images may be displayed at the HMI screen in order to assist the driver with the measurement information. Visual examples, see FIG. **12**, may be provided to aid the driver in identifying the location on the vehicle, the trailer or between the vehicle and trailer that the driver is being prompted to enter. In addition, numerical limits for the driver entered measurements are set within the trailer backup assist system and may be displayed to the driver. The driver may be warned about entered measurements that exceed the numerical limits. Additionally, the measurement information requests that the driver is prompted to enter may be presented to the driver in the order that the measurements should be entered into the trailer backup assist system.

It should be noted that while measurement information is discussed above as being entered by the driver, various methods of entering measurement information may also be employed without departing from the scope of the disclosed subject matter. For example, a system to automatically detect measurements using existing vehicle and trailer data including, but not limited to, vehicle speed, wheel rotation, steering wheel angle, vehicle to trailer relative angle, and a rate of change of the vehicle to trailer angle.

Examples of the measurement information may include a horizontal distance from the rear of the vehicle to the center of a hitch ball, a horizontal distance from the rear of the vehicle to a center of the target, a vertical distance from the target to the ground, and a horizontal offset of the target from a cen-

terline of the hitch ball. In the event the target is attached at other than the centerline of the hitch ball, then the trailer backup assist system must know which side of the vehicle the target is attached to, the passenger side or the driver side. A menu on the HMI may presented for the driver to indicate passenger side or driver side for the placement of the target. The trailer backup assist system also needs to know the horizontal distance from the rear of the vehicle to a center of the axle or axles of the trailer. The measurements may be entered in either English or Metric units.

The driver is presented **622** with the option to revise any of the measurements before proceeding with the setup process. Otherwise, the setup module **600** is complete **624** and the calibration module **700** begins.

The calibration module **700** is designed to calibrate the curvature control algorithm with the proper trailer measurements and calibrate the trailer backup assist system for any hitch angle offset that may be present. After completing the setup module **600**, the calibration module begins **700** and the driver is instructed **702** to pull the vehicle-trailer combination straight forward until a hitch angle sensor calibration is complete. The HMI may notify **704** the driver, by way of a pop up or screen display that the vehicle-trailer combination needs to be pulled forward until calibration is complete. When calibration is complete, the HMI may notify **704** the driver. Any hitch angle offset value is stored **706** in memory, accessed as necessary by the curvature control algorithm, and the calibration module **700** ends **704**.

It should be noted that while hitch angle calibration is described above as maybe requesting the driver pull forward information, various other methods of hitch angle calibration may also be employed without departing from the scope of the disclosed subject matter.

Upon completion of the setup module **600** and the calibration module **700**, the activation module **800** may begin. The activation module **800** is described with reference to FIG. **11**. The activation module **800** is designed to activate automatic steering of the vehicle during trailer backup assist operations. The driver is instructed **802** to place the vehicle in reverse. Upon activation of the trailer backup assist system, the steering system will not accept any steering angle commands from any source other than the trailer backup assist system **804**. The trailer setup **600** and calibration **700** modules must be completed and a current hitch angle must be within a predetermined operating range for the trailer backup assist system **806**. The vehicle speed must also be less than a predetermined activation speed **808**. In the event any one, or all, of these conditions **804**, **806**, **808** are not met, the driver is prompted to apply a corrective measure **810**. The driver must confirm **814** that the corrective action has been taken in order for the control module to begin. If a corrective action is taken, but the activation module deems it unacceptable, the driver will be instructed **810** to try another corrective action.

For steering systems where the steering wheel is directly coupled to the steered wheels of the vehicle, the driver cannot engage with the steering wheel during trailer backup assist. If any steering wheel motion is obstructed, by the driver or otherwise, the trailer backup assist system will present instructions **810** to the driver to remove their hands from the steering wheel. Activation **800** will be suspended or discontinued until the obstruction is removed. If the vehicle speed exceeds a threshold speed or if the vehicle hitch angle is not acceptable, the driver will be prompted **810** to take corrective action. Until corrective action is taken, accepted and acknowledged, the activation **800** and control **200**, **500** modules will be interrupted.

When the driver moves the gear shift from "park" to "reverse" **802** and presses or turns a trailer backup steering input apparatus **125** a rear view camera image may appear in a display of the HMI. If at any time during the reversing process the hitch angle becomes too large for the system to control the curvature of the trailer, the TBA will provide a warning to the driver to pull forward to reduce the hitch angle. If at any time during the reversing process the system is unable to track the hitch angle target, the driver is presented with instructions to correct the problem. If at any time the vehicle speed exceeds that predetermined activation speed, the driver is visually and audibly warned to stop or slow down.

When all of the conditions of the activation module are met and maintained, the control module may begin. The control module executes the directives described above with reference to FIGS. **5** and **7**. However, the activation module **800** includes a monitoring function **816** so that, if at any time during execution of the control module **200**, **500** the control is interrupted, the driver is instructed to make necessary corrections. In the event any one of the necessary corrections are not made, the control of the vehicle by way of the trailer backup assist system will end. The driver may also intentionally end the control by exiting the system through a menu selection on the HMI or placing the vehicle in a gear setting that is other than "park" or "reverse".

Referring now to instructions processible by a data processing device, it will be understood from the disclosures made herein that methods, processes and/or operations adapted for carrying out trailer backup assist functionality as disclosed herein are tangibly embodied by non-transitory computer readable medium having instructions thereon that are configured for carrying out such functionality. The instructions are tangibly embodied for carrying out the method **200**, **500**, **600**, **700** and **800** disclosed and discussed above and can be further configured for limiting the potential for a jackknife condition such as, for example, by monitoring jackknife angle through use of the equations discussed in reference to FIGS. **5** and **7** and/or by implementing jackknife countermeasures functionality discussed above in reference to FIG. **8**. The instructions may be accessible by one or more data processing devices from a memory apparatus (e.g. RAM, ROM, virtual memory, hard drive memory, etc.), from an apparatus readable by a drive unit of a data processing system (e.g., a diskette, a compact disk, a tape cartridge, etc.) or both. Accordingly, embodiments of computer readable medium in accordance with the disclosed subject matter include a compact disk, a hard drive, RAM or other type of storage apparatus that has imaged thereon a computer program (i.e., instructions) configured for carrying out trailer backup assist functionality in accordance with the disclosed subject matter.

In a preferred embodiment of the disclosed subject matter, a trailer back-up assist control module (e.g., the trailer back-up assist control module **120** discussed above in reference to FIG. **1**) comprises such a data processing device, such a non-transitory computer readable medium, and such instructions on the computer readable medium for carrying out trailer backup assist functionality (e.g., in accordance with the method **200** discussed above in reference to FIG. **2**) and/or the method **500** discussed above in reference to FIG. **8** and/or the methods **600**, **700** and **800** discussed above in reference to FIGS. **10** and **11**. To this end, the trailer back-up assist control module can comprise various signal interfaces for receiving and outputting signals. For example, a jackknife enabling condition detector can include a device providing hitch angle information and hitch angle calculating logic of the trailer back-up assist control module. A trailer back-up assist control

module in the context of the disclosed subject matter can be any control module of an electronic control system that provides for trailer back-up assist control functionality in accordance with the disclosed subject matter. Furthermore, it is disclosed herein that such a control functionality can be implemented within a standalone control module (physically and logically) or can be implemented logically within two or more separate but interconnected control modules (e.g., of an electronic control system of a vehicle) In one example, trailer back-up assist control module in accordance with the disclosed subject matter is implemented within a standalone controller unit that provides only trailer backup assist functionality. In another example, trailer backup assist functionality in accordance with the disclosed subject matter is implemented within a standalone controller unit of an electronic control system of a vehicle that provides trailer backup assist functionality as well as one or more other types of system control functionality of a vehicle (e.g., anti-lock brake system functionality, steering power assist functionality, etc.). In still another example, trailer backup assist functionality in accordance with the disclosed subject matter is implemented logically in a distributed manner whereby a plurality of control units, control modules, computers, or the like (e.g., an electronic control system) jointly carry out operations for providing such trailer backup assist functionality.

Maximum Controllable Trailer Path Curvature

While backing the trailer, a maximum allowable trailer path curvature should not be exceeded. The maximum allowable trailer path curvature is determined by the trailer backup assist system using trailer dimensions. Should the trailer path curvature exceed the maximum allowable value while the vehicle is backing the trailer, the hitch angle $\gamma(j)$ may become sufficiently large and contact may occur between a portion of the trailer and a portion of the vehicle. It is possible that a driver may have entered inaccurate measurements for trailer dimensions into the trailer backup assist system **105** resulting in an incorrect maximum allowable trailer path curvature determination by the trailer backup assist system **105**. The result is that the system **105** could possibly steer the trailer past a controllable curvature path because the maximum controllable trailer path curvature may have been determined using the inaccurate trailer measurements.

As discussed above, a jackknife enabling condition can arise based on current operating parameters of a vehicle in combination with a corresponding trailer angle and a trailer path curvature. This condition can be indicated when one or more specified vehicle operating thresholds are met while a particular trailer angle is present. For example, although the particular trailer angle is not currently at the jackknife angle for the vehicle and attached trailer, certain vehicle operating parameters can lead to a rapid (e.g., uncontrolled) transition of the trailer angle to the jackknife angle for a current commanded trailer path curvature and/or can reduce an ability to steer the trailer away from the jackknife angle. One reason for a jackknife enabling condition is that trailer curvature control mechanisms (e.g., those in accordance with the inventive subject matter) generally calculate steering commands for the vehicle at an instantaneous point in time during backing of a trailer. However, these calculations will typically not account for lag in the steering control system of the vehicle (e.g., lag in a steering EPAS controller).

The maximum controllable trailer path curvature may be determined as described hereinafter. In certain instances, such as described above with reference to FIG. **12**, the driver provides the trailer backup assist system **105** with D, the distance from the hitch to the trailer axle and L, the distance from the hitch to the vehicle rear axle by entering the values into the system by way of the HMI. W, the vehicle wheelbase, is programmed into the system and δ, the steering angle of the vehicle front wheels and γ, the hitch angle, are typically measured using vehicle sensors. The values D, L, W, δ, and γ are used to calculate the steering angle limit for the steered front wheels such that the hitch angle, γ, will not exceed the jackknife angle, $\gamma(j)$, which is also referred to as the critical hitch angle. Therefore, under a limitation that the hitch angle, γ, may not exceed the jackknife angle, $\gamma(j)$, and the jackknife angle is the hitch angle that maintains a circular motion for the vehicle-trailer combination when the steered wheels of the vehicle are at a maximum steering angle, $\delta(max)$.

In the event the driver enters erroneous measurements for L and D into the trailer backup assist system **105**, the critical hitch angle being used by the system may in fact be incorrect, and the system may potentially be steered beyond the maximum controllable trailer path curvature or beyond the critical hitch angle, $\gamma(j)$. A determination may be made that detects measurements entered by the driver to be incorrect and that the potential for error exists. This determination may be made upon observations of a magnitude of the hitch angle, γ, which grows as the vehicle is reversed using the maximum steering angle, $\delta(max)$. When the hitch angle, γ, is continuing to increase in magnitude even while the vehicle is at the maximum steering angle, $\delta(max)$, the determination may be made that one, or more, of the measurements entered by the driver may be incorrect and need to be addressed by the driver.

Referring to FIG. **13** a portion of the trailer backup assist system **105** is shown including the steering input apparatus **125**, the hitch angle detecting apparatus **130** and the steering angle detecting apparatus **140**. A camera **20** is shown as an input for providing video images to the trailer backup assist control module **120** as well as the vehicle HMI **25**. The camera **20** may be a rearview camera mounted on the tow vehicle in a position and orientation to acquire images of the trailer towed by the vehicle rearward of the vehicle. The camera **20** may include an imaging camera that generates one or more camera images of the trailer including the hitch angle.

The trailer backup assist system **105** may communicate with one or more devices that include, but are not limited to, vehicle exterior alerts **24** such as vehicle brake lights, emergency flashers, or a vehicle horn for providing visual and audible alerts to the driver. Additionally, the trailer backup assist system **105** may communicate with one or more vehicle human machine interfaces (HMI's) **25** including a vehicle display such as a center stack mounted navigation/entertainment display. Further, the trailer backup assist system may communicate by way of wireless communication **22** with one or more handheld or portable devices **26**, such as a smartphone. The portable device **26** may include a display **28** for displaying one or more images of the trailer and the hitch angle. In addition, the portable device **26** may provide feedback information about the hitch angle including visual and audible alerts.

Referring still to FIG. **12** the trailer backup assist control module **120** calculates **602** the critical hitch angle $\gamma(j)$ and a maximum controllable curvature limit (curvature limit) **604** using the measurements entered by the driver. As the trailer backup assist system **105** implements a trailer backup assist request, the hitch angle is monitored **216** (see FIG. **4**) for an unacceptable hitch angle condition that is a hitch angle beyond the critical hitch angle. And trailer curvature commands are monitored for an unacceptable trailer curvature command that is beyond the maximum controllable curvature limit **604**. An unacceptable trailer angle condition occurs when the vehicle steering angle reaches maximum angle but is unable to reduce the trailer angle, i.e., the hitch angle

continues to increase. Upon such a determination, the trailer backup assist control module will reset **608** the maximum allowable curvature limit to a default maximum controllable curvature limit which is a value not dependent upon the driver entered measurements that is known to be controllable by the steering system for any generic trailer dimensions. The reset **608** to a default maximum controllable curvature limit also includes resetting the critical hitch angle to a default value that will be incorporated into the calibration of the curvature control algorithm until the point in time that corrected trailer measurements are entered by the driver.

The trailer backup assist control module will initiate **610** a warning to the driver that the driver entered measurements are incorrect. The trailer backup assist control module will instruct **612** the driver to pull the vehicle forward in order to reduce the trailer angle. And the trailer backup assist control module will inform **614** the driver that the measurements entered during the setup need to be checked, corrected and re-entered.

Communication with the driver will most likely take place by way of the HMI using audible and visual messages that will be broadcast and displayed to the driver. It is also possible that the messages may be communicated via wireless communication **22** to the portable device **26**.

Once the driver enters corrected dimensions, critical hitch angle and maximum controllable curvature values are determined and applied in the calibration module, and the maximum trailer allowable controllable curvature during backing of the trailer by the vehicle is limited by the trailer backing control algorithm of the trailer backup assist system **105** using the calculated maximum controllable curvature limit **604**. The constraint limiting the curvature control to stay within the maximum allowable trailer curvature will ensure that the desired trailer curvature input will not exceed the steering limits of the vehicle.

In the foregoing specification, the disclosed subject matter has been described with reference to specific exemplary embodiments. Various modifications and changes may be made, however, without departing from the scope of the disclosed subject matter as set forth in the claims. The specification and figures are illustrative, rather than restrictive, and modifications are intended to be included within the scope of the disclosed subject matter. Accordingly, the scope of the disclosed subject matter should be determined by the claims and their legal equivalents rather than by merely the examples described.

For example, the steps recited in any method or process claims may be executed in any order and are not limited to the specific order presented in the claims. The equations may be implemented with a filter to minimize effects of signal noises. Additionally, the components and/or elements recited in any apparatus claims may be assembled or otherwise operationally configured in a variety of permutations and are accordingly not limited to the specific configuration recited in the claims.

Benefits, other advantages and solutions to problems have been described above with regard to particular embodiments; however, any benefit, advantage, solution to problem or any element that may cause any particular benefit, advantage or solution to occur or to become more pronounced are not to be construed as critical, required or essential features or components of any or all the claims.

The terms "comprise", "comprises", "comprising", "having", "including", "includes" or any variation thereof, are intended to reference a non-exclusive inclusion, such that a process, method, article, composition or apparatus that comprises a list of elements does not include only those elements recited, but may also include other elements not expressly listed or inherent to such process, method, article, composition or apparatus. Other combinations and/or modifications of the above-described structures, arrangements, applications, proportions, elements, materials or components used in the practice of the disclosed subject matter, in addition to those not specifically recited, may be varied or otherwise particularly adapted to specific environments, manufacturing specifications, design parameters or other operating requirements without departing from the general principles of the same.

The invention claimed is:

1. A trailer backup assist system on a vehicle having an attached trailer, the system comprising:

a human machine interface device in communication with a controller of the trailer backup assist system;

a setup module receiving trailer measurements entered at the human machine interface by a driver;

a calibration module applying the trailer measurements received by the setup module to calculate a maximum controllable curvature limit, a critical hitch angle and calibrate a curvature control algorithm associated with the trailer backup assist system;

an activation module for activating a steering system on the vehicle during reverse movement of the vehicle-trailer combination;

a trailer backup steering input apparatus having a rotatable control element positionable at a zero curvature command position and at positions within opposing rotational ranges of motion relative to the zero curvature commanding position and generating driver request for a trailer path curvature command that is less than the calculated maximum controllable curvature limit and is a function of at least one of an amount of rotation of the rotatable control element with respect to the zero curvature commanding position, a rate movement of the rotatable control element, and a direction of movement of the rotatable control element with respect to the zero curvature commanding position; and

a control module to receive the driver request, implement the curvature control algorithm, provide steering commands to the steering system to control the reverse movement of the vehicle-trailer combination in a manner consistent with the driver request, and implement a jackknife counter-measure by altering at least one vehicle operating parameter that increases a radius of a curvature path of the trailer and inhibits a decrease in the radius of the curvature path of the trailer, the steering commands during reverse movement of the vehicle-trailer combination are limited to those provided by the control module;

the control module to monitor an output of a steering angle sensor and detect a maximum vehicle steering angle, the control module to monitor an output of the hitch angle sensor and upon detection of an increasing output of the hitch angle sensor while the vehicle steering angle is at the maximum vehicle steering angle, the control module to reset the calculated maximum controllable curvature limit for the curvature control algorithm with a default maximum controllable curvature limit.

2. The system as claimed in claim **1** further comprising the control module to reset the critical hitch angle to a default maximum controllable angle.

3. The system as claimed in claim **1** further comprising the control module to implement a warning to the driver when the calculated maximum controllable curvature limit is reset.

4. The system as claimed in claim 3 further comprising the warning to the driver being displayed at the human machine interface.

5. The system as claimed in claim 4 wherein the setup module further comprises a menu displayed by the human machine interface device that provides an opportunity to revise the trailer measurements received by the setup module.

6. The system as claimed in claim 3 further comprising the warning to the driver being wirelessly transmitted to a portable device.

7. The system as claimed in claim 3 wherein the warning further comprises instructions to enter corrected trailer measurements, the corrected trailer measurements being entered by the driver, received by the setup module, and applied by the calibration module.

8. The system as claimed in claim 3 further comprising instructions to the driver to apply a corrective action.

9. The system as claimed in claim 8 wherein the corrective action is to pull the vehicle forward and prompt the driver to enter corrected trailer measurements.

10. A method for implementing a trailer backup assist system on a vehicle having an attached trailer, the method carried out in a controller associated with the trailer backup assist system and comprising the steps of:

receiving trailer measurements representative of representative of dimensions on the trailer, on the vehicle and between the trailer and the vehicle;

calculating a maximum controllable curvature and a critical hitch angle using the received trailer measurements;

calibrating a curvature control algorithm and a hitch angle sensor associated with the trailer backup assist system in accordance with the received trailer measurements, the calculated maximum controllable curvature limit, the calculated critical hitch angle, and a maximum vehicle steering angle;

activating a steering system on the vehicle after calibrating the curvature control algorithm and the hitch angle sensor;

receiving a driver request to control reverse movement of the vehicle-trailer combination according to a desired trailer path curvature;

implementing the curvature control algorithm to provide steering commands to the steering system in response to the driver request, the steering commands during reverse movement of the vehicle-trailer combination are limited to those provided by the curvature control algorithm;

monitoring a vehicle steering angle sensor to detect when the vehicle has reached the maximum vehicle steering angle;

monitoring the hitch angle sensor to determine when a hitch angle is increasing while the vehicle is being steered at the maximum vehicle steering angle; and

replacing the calculated maximum controllable curvature with a default maximum controllable curvature limit;

re-calibrating the curvature control algorithm using the default maximum controllable curvature limit; and

initiating a warning to the driver that the received trailer measurements used in calibrating the curvature control algorithm are incorrect.

11. The method as claimed in claim 10 further comprising the step of replacing the critical hitch angle with a default maximum controllable angle and the step of re-calibrating the curvature control algorithm further comprises re-calibrating the curvature control algorithm with the default maximum controllable angle.

12. The method as claimed in claim 10 wherein the step of initiating a warning to the driver further comprises displaying the warning on a human machine interface on the vehicle.

13. The method as claimed in claim 10 wherein the step of initiating a warning to the driver further comprises wirelessly communicating the warning to a portable device.

14. The method as claimed in claim 10 wherein the step of initiating a warning further comprises a instructing the driver that a corrective action is required.

15. The method as claimed in claim 14 wherein the step of instructing the driver further comprises instructing the driver to pull the vehicle forward and enter corrected trailer measurements.

16. The method as claimed in claim 15 further comprising the step of re-calibrating the curvature control algorithm using corrected trailer measurements.

17. A trailer backup assist system on a vehicle having an attached trailer comprising:

a human machine interface device in communication with a controller;

a setup module to receive trailer measurements at the controller;

a calibration module to apply the trailer measurements to calibrate a curvature control algorithm according to a calculated maximum controllable curvature limit and a calculated critical hitch angle calculated using the received trailer measurements;

an activation module to activate a steering system on the vehicle during reverse movement of the vehicle-trailer combination;

a control module to receive a driver request for a trailer path curvature command, to implement the curvature control algorithm and to provide steering commands to the steering system in response to the driver request to control the reverse movement of the vehicle-trailer combination in a manner consistent with the driver request, the steering commands during reverse movement of the vehicle-trailer combination being limited by those provided by the calculated maximum controllable curvature;

the control module to monitor an output of the steering angle sensor to detect when the vehicle is being steered at a maximum vehicle steering angle;

the control module to monitor an output of the hitch angle sensor to detect when the hitch angle continues to increase despite the vehicle being steered at the maximum vehicle steering angle; and

the control module to initiate a warning to the driver in response to detecting the hitch angle continues to increase while the vehicle is being steered at the maximum vehicle steering angle.

18. The system as claimed in claim 17 further comprising the control module to replace the calculated maximum controllable curvature with a default maximum controllable curvature.

19. The system as claimed in claim 18 further comprising the control module to replace the calculated critical hitch angle with a default maximum controllable angle.

20. The system as claimed in claim 17 further comprising the control module to instruct the driver to apply corrective measures.

21. The system as claimed in claim 20 wherein the corrective measures further comprise pulling the vehicle forward and entering corrected trailer measurements to be received at the setup module.

22. The system as claimed in claim 20 wherein the control module instructs the driver by way of a display at a human machine interface on the vehicle.

23. The system as claimed in claim 20 wherein the control module instructs the driver by way of wirelessly communicating with a portable device.

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